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BEACH CHANGES CAUSED BY THE ATLANTIC COAST STORM OF 17 DECEMBER--ETC(U)
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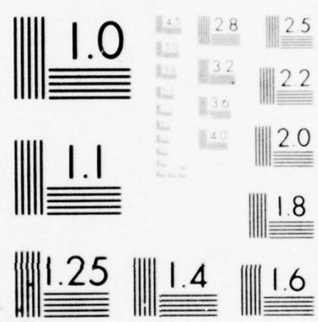

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Beach Changes Caused by the Atlantic Coast Storm of 17 December 1970

by

Allan E. DeWall, Patricia C. Pritchett, and Cyril J. Galvin, Jr.

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A low-pressure system with 20- to 35-knot winds caused waves up to 11 feet high and tides up to 3.6 feet above normal along Atlantic coast beaches, North Carolina to New England, from 16 to 18 December 1970. Ninety-one beach profile lines were surveyed from dune to low tide terrace within 2 weeks before the storm and immediately after the storm; sand levels at pipes along selected profile lines were measured during the storm. Comparison of before-and-after surveys indicates that 80 percent of the profile lines

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showed a net loss of sand above mean sea level (MSL). Profiles to wading depth showed accretion below MSL in most cases. The profile line exhibiting maximum erosion (21.7 cubic yards per foot) occurred at Cape Cod, Massachusetts; maximum accretion (24.4 cubic yards per foot) was found at Atlantic City, New Jersey. Maximum vertical changes in sand level (4 to 5 feet) were observed on coarser, steeper beaches (Cape Cod and Westhampton Beach, New York), and maximum horizontal changes in the position of the MSL contour (-96.3 feet) were observed on finer, flatter beaches (Ludlam Island, New Jersey). Extrapolation from surveyed profiles indicates that a minimum of 10.1 X 10^6 cubic yards of sand was moved from the beach above MSL along 450 miles of ocean front between Cape May, New Jersey, and Race Point, Massachusetts, by this storm. The intensity of the storm is estimated to be equaled or exceeded twice a year.

10.1 million

PREFACE

This report provides coastal engineers with a study of the effect of a moderately severe northeast storm on Atlantic coast beaches from Cape Cod, Massachusetts, to Cape May, New Jersey, 17 December 1970. This report is also the source for most of the data in Table 4-5 of the Shore Protection Manual (U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1975). The work was carried out under the Beach Evaluation Program (BEP) of the U.S. Army Coastal Engineering Research Center (CERC).

The report was prepared by Allan E. DeWall, Patricia C. Pritchett, and Cyril J. Galvin, Jr., respectively, Geologist, Oceanographer, and Chief, Coastal Processes Branch, CERC, under the general supervision of R.P. Savage, Chief, Research Division, CERC.

The authors acknowledge the contributions of the following individuals and organizations: Beach profile surveys and other data from the U.S. Army Engineer Division, New England, and U.S. Army Engineer Districts, New York and Philadelphia; pipe profile and visual wave observations made by volunteer observers: Neil Ackerson, Dennis Galvin, Larry McCormick, Mitchell Granat, Peter Kief, Joseph Lawless, Charles McDonnell, Bill Stafford, Larry Tillman, John Wilk, and Howard Wright. Profile data reduction and analysis were provided by the following CERC personnel: Dr. Craig Everts, Linda Mintz, Ralf Kohler, David Mowrey, William Seelig, Leon Tenney, Barry Sims, and John Buchanan. Poststorm inspections were conducted with the assistance of Edward Thompson, Ray Bodine, Marc Koenig, and Gilbert Nersesian.

Comments on this publication are invited.

Approved for publication in accordance with Public Law 166, 79th Congress, approved 31 July 1945, as supplemented by Public Law 172, 88th Congress, approved 7 November 1963.

John H. Cousins

JOHN H. COUSINS
Colonel, Corps of Engineers
Commander and Director

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	by	To obtain
inches	25.4	millimeters
	2.54	centimeters
square inches	6.452	square centimeters
cubic inches	16.39	cubic centimeters
feet	30.48	centimeters
	0.3048	meters
square feet	0.0929	square meters
cubic feet	0.0283	cubic meters
yards	0.9144	meters
square yards	0.836	square meters
cubic yards	0.7646	cubic meters
miles	1.6093	kilometers
square miles	259.0	hectares
knots	1.8532	kilometers per hour
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
millibars	1.0197×10^{-3}	kilograms per square centimeter
ounces	28.35	grams
pounds	453.6	grams
	0.4536	kilograms
ton, long	1.0160	metric tons
ton, short	0.9072	metric tons
degrees (angle)	0.1745	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins[1]

[1] To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use formula: $K = (5/9)(F - 32) + 273.15$.

BEACH CHANGES CAUSED BY THE ATLANTIC COAST STORM OF 17 DECEMBER 1970

by
Allan E. DeWall, *Patricia C. Pritchett*, and *Cyril J. Galvin, Jr.*

I. INTRODUCTION

On 17 December 1970 a storm of moderate intensity affected the Atlantic coast from North Carolina to New England. This report relates characteristics of this coastal storm to the resulting beach changes at selected localities. As part of the U.S. Army Coastal Engineering Research Center (CERC) Beach Evaluation Program (BEP), 91 beach profile lines at seven localities between Cape Cod, Massachusetts, and Cape May, New Jersey (Fig. 1), were surveyed from the frontal dune or bulkhead to the low tide terrace before and after the storm. The variables analyzed and discussed include: (a) Environmental measurements of the storm's intensity, including winds, waves, and tidal heights; (b) beach changes, including the change in horizontal position of the mean sea level (MSL) contour, and the change in area above MSL between the prestorm and poststorm profiles; and (c) correlations between the storm characteristics and resulting beach changes.

DeWall, Pritchett, and Galvin (1971) is a condensed version of the present report. Additional information on the BEP and the 17 December storm is given in Galvin (1968), Pritchett (1971), and DeWall (1972). The present report contains revised estimations of some data in the earlier reports, and is the source for most of the data in Table 4-5 of U.S. Army, Corps of Engineers, Coastal Engineering Research Center (1975).

II. METEOROLOGY OF STORM

1. Characteristics and Path of Low-Pressure System.

The storm began as a low-pressure area over northeastern New Mexico on 14 December 1970. By 2200 hours e.s.t. on the 15th, the center of the low had crossed Texas and Oklahoma and was on a northeastern path across Arkansas (Fig. 2). It continued on this trajectory until reaching southern Indiana where it turned eastward, moving toward the coast. Late on the evening of the 16th, the center passed over Salisbury, Maryland, and began heading northeast, crossing the Delmarva Peninsula and moving out over the ocean. At 0400 hours on the 17th, the low was centered just off Cape May; the central pressure was about 998 millibars. Six hours later the low, centered off New York began to strengthen (deepen). The pressure dropped to 992 millibars as is passed Nantucket, Massachusetts. As the low began moving east-northeast, the distance between the coast and the center increased. On the afternoon of the 18th, the center passed over Nova Scotia, and then continued toward Greenland.

2. Windspeed and Wind Direction.

Wind vectors for Atlantic City, New Jersey, New York City, Boston, Massachusetts, and Portland, Maine, are presented in Figure 3. The

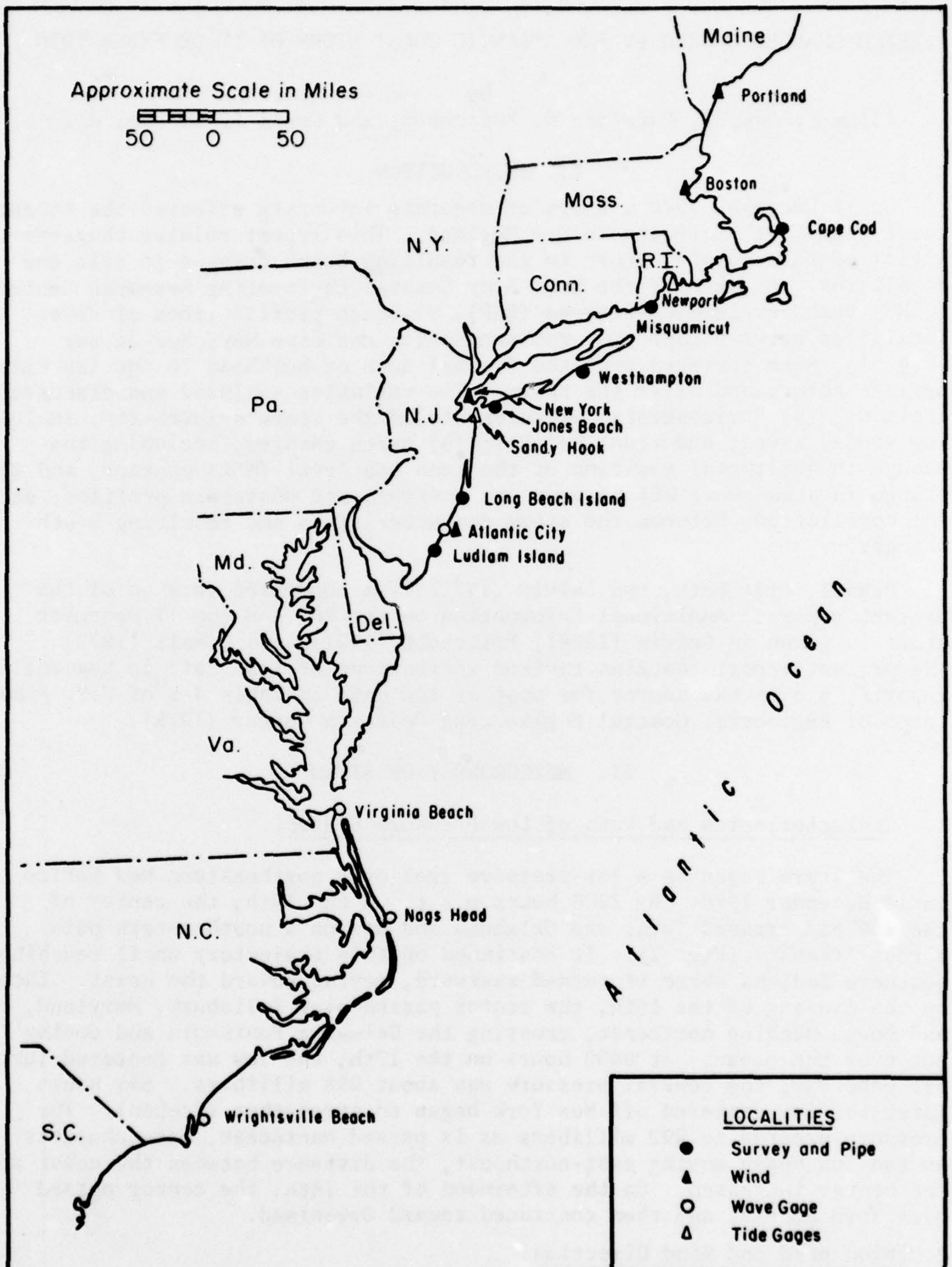


Figure 1. Data-contributing localities to the 17 December 1970 storm.

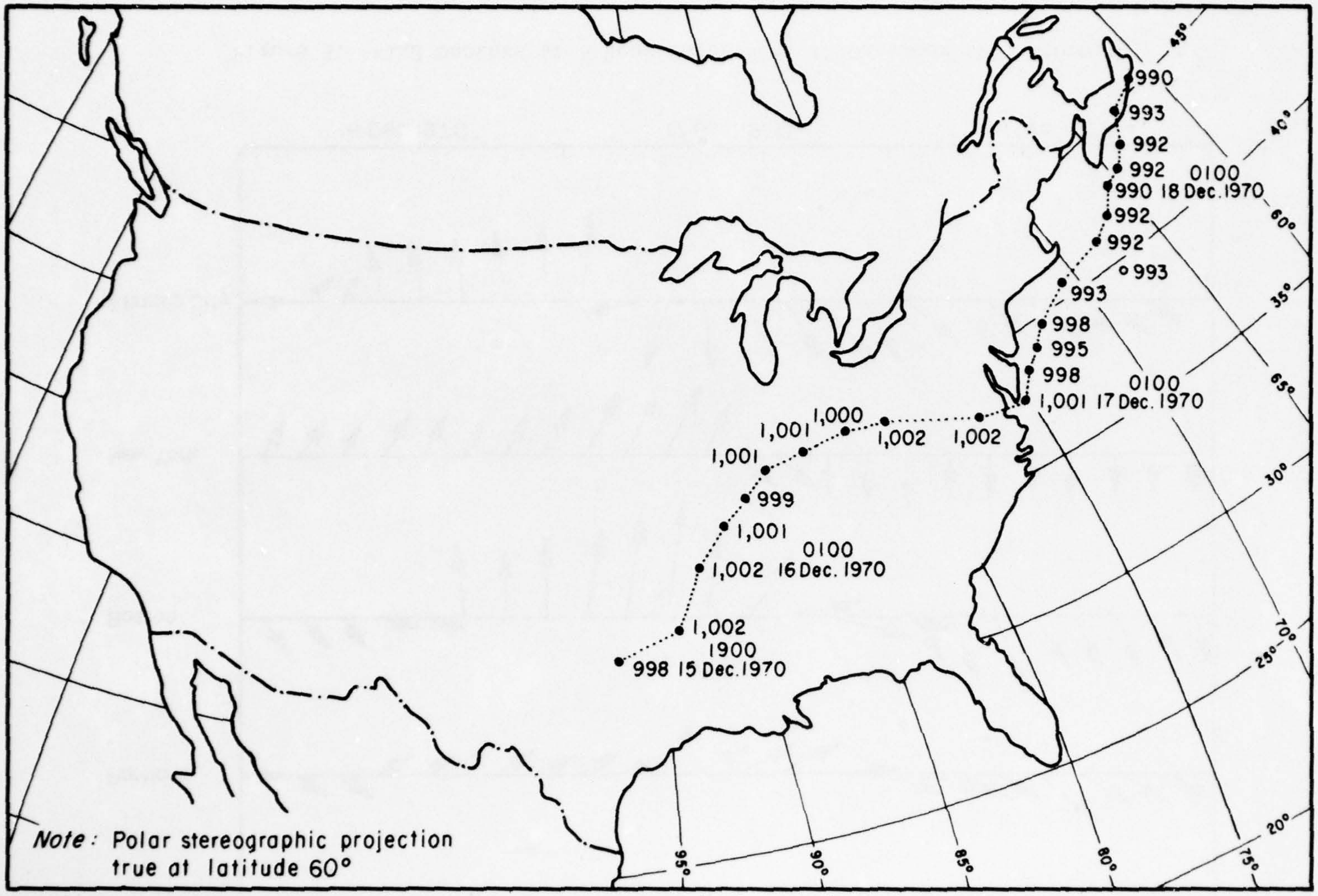


Figure 2. Storm track of low-pressure centers (mbar) at 3-hour intervals (e.s.t.), 15 to 18 December 1970.

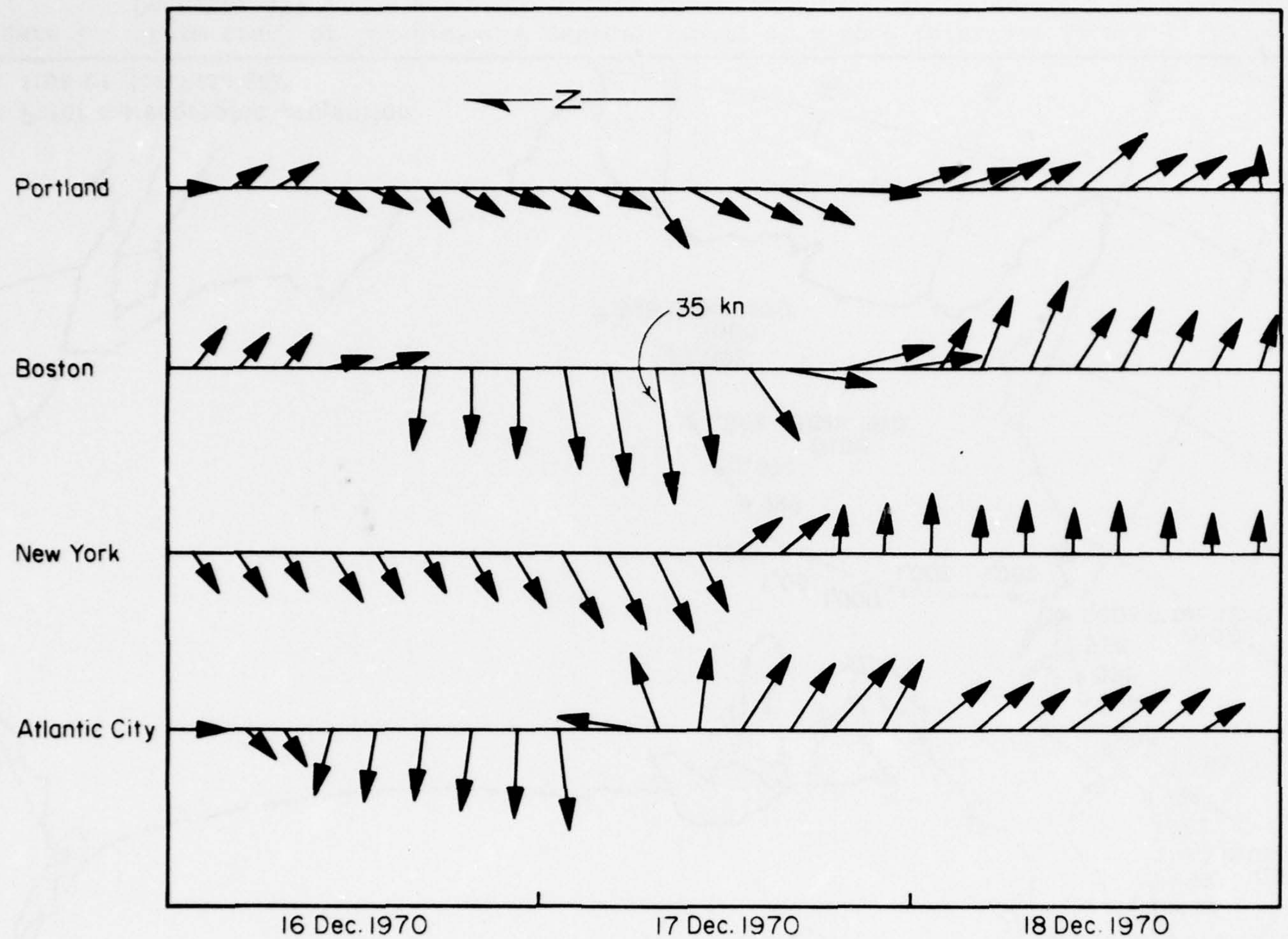


Figure 3. Wind vectors at 3-hour intervals, 17 December 1970 storm.

windspeed at these localities usually reached a maximum shortly before the center of the low passed up the coast; e.g., maximum winds at Atlantic City (22 knots from the northeast) occurred shortly after 2400 hours on the morning of 17 December. At that time, the direction of the wind began changing, from easterly to northwesterly, as the center of the low moved up the coast. Similar changes in wind direction occurred later that morning as the low passed offshore of New York and Boston. At Boston, the maximum windspeeds that preceded the passage of the front (35 knots) were the highest recorded during the 3-day period at the four localities.

The Portland wind record was more variable with maximum windspeeds occurring after the storm passed. The change in direction, indicating the passage of the low, occurred shortly after 1600 hours on 17 December.

Generally, as the low moved up the coast, it was preceded by strong winds from the northeast and followed by a shift in the wind direction (from the northwest), causing slightly weaker winds.

III. WAVES, TIDES, AND SURGE

1. Waves.

During the storm, wave variables were recorded by CERC wave gages and visually observed. Detailed wave data for the storm period, including gage data, BEP visual data, and visual surf observations from the U.S. Army-Coast Guard Cooperative Surf Observation Program, are reported in Pritchett (1971).

Gage data were taken for 7 minutes at 4-hour intervals at Atlantic City, Virginia Beach, Virginia, and Wrightsville Beach and Nags Head, North Carolina. Each 7-minute record was analyzed, and the wave period calculated from the regular waves; then, all the heights were ordered and the highest one-third was averaged to yield a significant wave height (Fig. 4) (Thompson and Harris, 1972). In addition to gage data, visual estimates of wave height, period, breaker type, and direction were made, usually once a day at selected localities.

Gage data from Atlantic City show that the maximum significant wave height (11 feet) and maximum period (12 seconds) occurred on the morning of 17 December. These were the largest values recorded on the Atlantic coast by the gages during the 3-day period. The maximum wave height dropped off rapidly to a more normal value after passage of the storm center; the period remained near its maximum until 1200 hours, 19 December.

Virginia Beach, the next gage station south of Atlantic City, reached its height maximum 6 hours earlier than Atlantic City, followed several hours later by the period maximum. The height maximum at Wrightsville Beach also occurred earlier, but was smaller than at Virginia Beach.

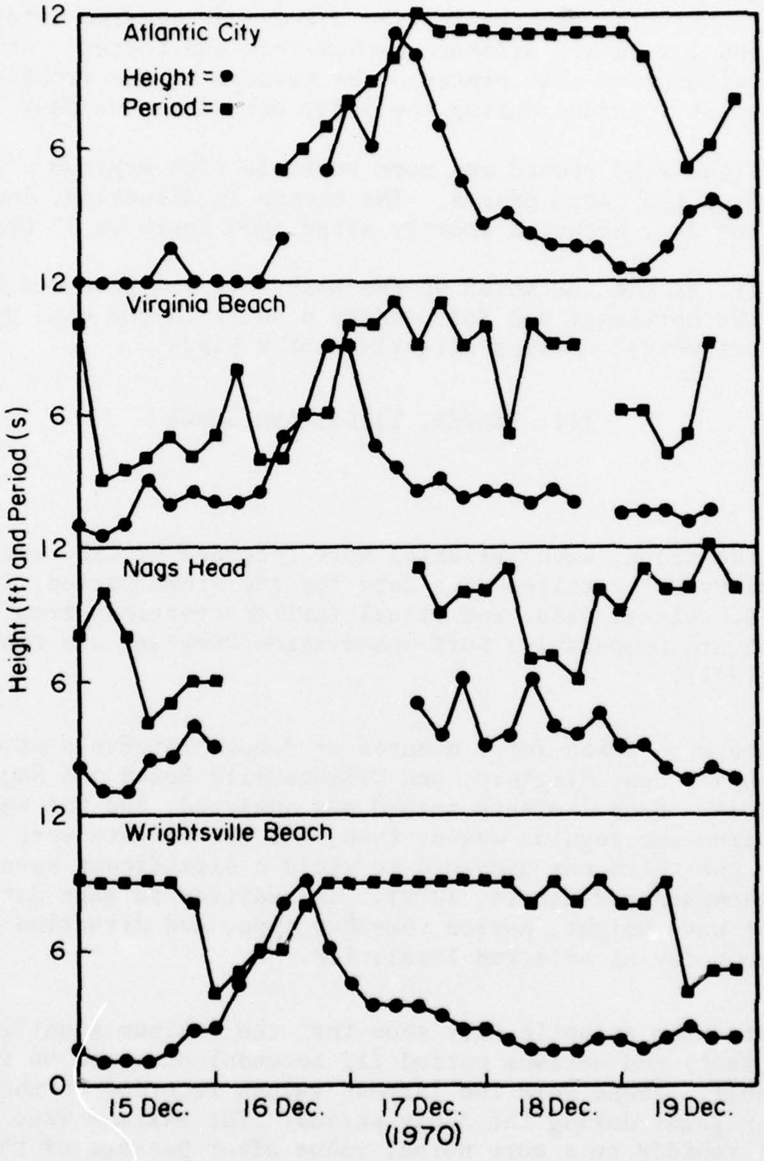


Figure 4. Wave gage period and height, 15 to 19 December 1970.

There were no gages located north of Atlantic City. Visual observations made at localities north of Atlantic City included maximum heights of 10 feet at Jones Beach, New York (1000 hours, 17 December), and at Cape Cod (Le Count Hollow) (1200 hours, 18 December). Volunteer observers reporting by telephone on the 17th and CERC field crews out on the beaches on the 18th did not observe wave heights greater than 10 feet.

2. Storm Surge.

Tide data were examined from the following stations: Sandy Hook, New Jersey, Newport, Rhode Island, and Boston (Fig. 1). The predicted and measured tides for these locations on 16, 17, and 18 December are shown in Figure 5. The greatest difference between predicted and measured tides at the three tidal gage stations occurred at Sandy Hook at 0400 hours on 17 December. This was a storm surge of 3.6 feet. At Newport, the maximum storm surge was 2.8 feet at 1000 hours on the 17th; at Boston, the storm surge was only about 2 feet, occurring early in the afternoon on the 17th.

Above normal tides at Sandy Hook lasted approximately 48 hours, from the beginning of the 16th to the end of the 17th. The duration of the elevated tides at the other two locations was about the same, but later in time. The maximum tides at Sandy Hook were about 1.5 feet higher than the springtides that occurred on the 12th and the 28th of December. Damage probably would have been greater had the storm occurred at the time of the springtides.

3. Wave Direction.

Estimates of the direction of breaking waves during the week of 13 December at 12 localities between Cape Cod and Assateague Island are summarized in Figure 6. The average wave direction is expressed in a code diagrammed at the top of the figure. Because of the different orientations of the beaches observed, direction relative to true north is not specified. The data indicate that waves were approaching the coast north of east before the passage of the storm, and south of east after the storm, which generally agrees with the wind patterns during that period.

IV. BEACH SURVEYS

1. Background.

The effect of the storm was measured from surveys at the following seven BEP localities: In north-to-south order, Cape Cod, Massachusetts; Misquamicut, Rhode Island; Westhampton Beach and Jones Beach on the south shore of Long Island, New York; and Long Beach Island, Atlantic City, and Ludlam Island in southern New Jersey. The surveys were done by surveying crews from the U.S. Army Engineer Division, New England (Cape Cod and Misquamicut), and U.S. Army Engineer Districts, New York (Westhampton Beach and Jones Beach) and Philadelphia (Long Beach Island,

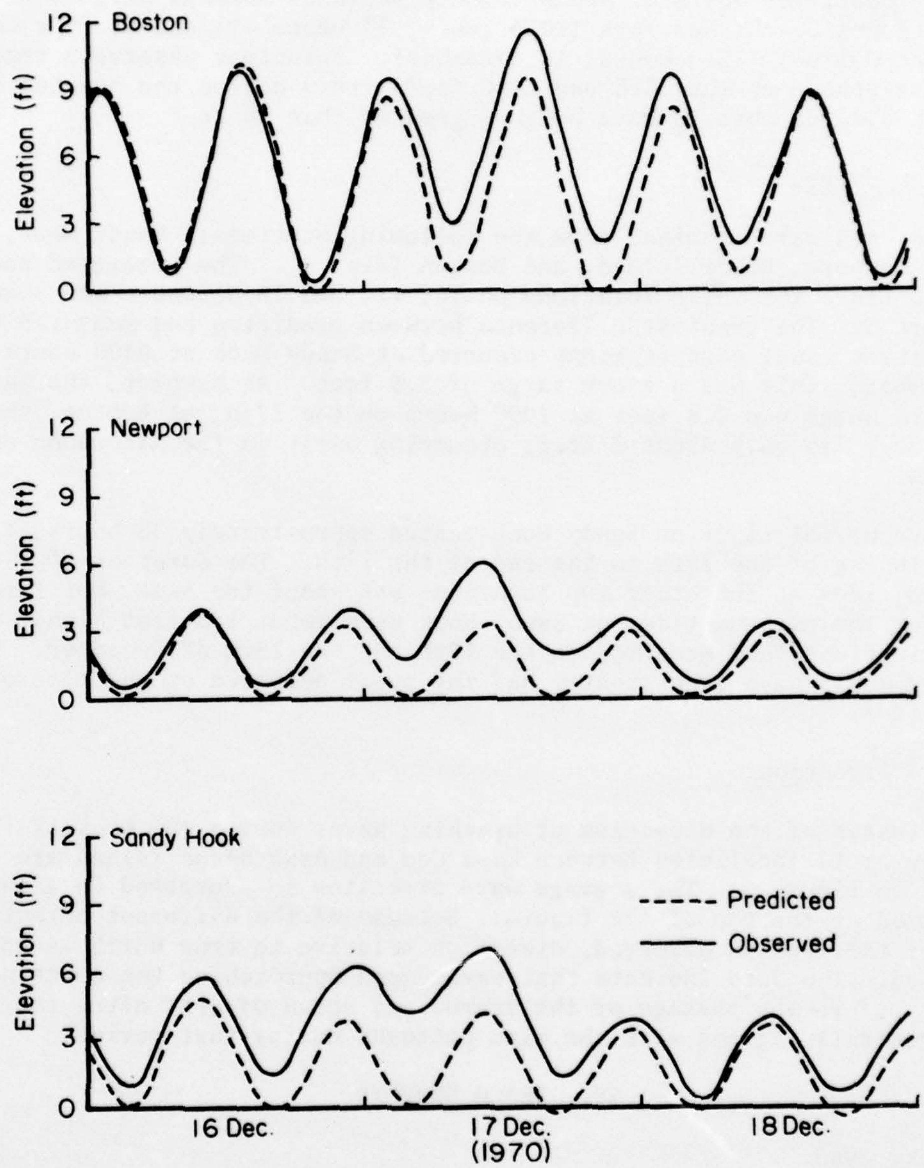
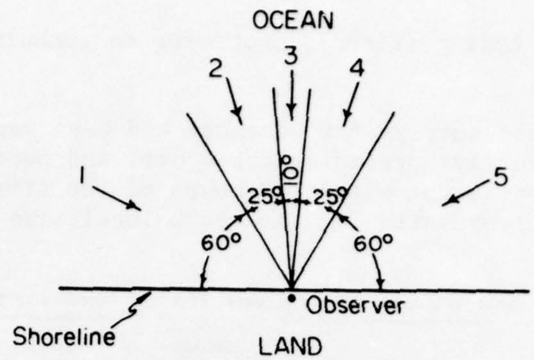


Figure 5. Observed and predicted tides, 17 December 1970 storm.



Wave Direction Code For Waves At Breaking

Date	No. Of Obsns.	Direction Code Avg.
13 Dec. 1970	6	2.2
14 Dec. 1970	7	3.3
15 Dec. 1970	6	2.7
16 Dec. 1970	8	1.9
17 Dec. 1970	5	2.2
18 Dec. 1970	31	2.5
19 Dec. 1970	17	3.8

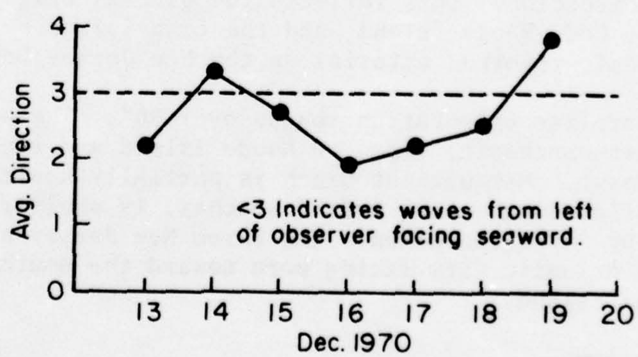


Figure 6. Wave direction at 12 east coast localities, week of 13 December 1970.

Atlantic City, and Ludlam Island), according to techniques described by Czerniak (1973).

Scheduled monthly surveys for December had been made at all seven localities within 16 days preceding the storm, and poststorm surveys were made at all but Misquamicut within 48 hours of the storm passage. The before-and-after survey dates for the seven localities are shown in Table 1.

Table 1. Before-and-after BEP survey dates of the 17 December 1970 storm.

Locality	December																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Cape Cod										X								X						
Misquamicut									X								S							X
Westhampton	X																T		X					
Jones Beach												X					O R			X				
Long Beach							X										M	X						
Atlantic City									X									X						
Ludlam Island										X								X						

2. Beach Characteristics.

The environmental factors characterizing each locality are summarized in Table 2. Generally, the shores change from low barrier beaches in southern New Jersey to steep, cliffed shorelines on Cape Cod. These shore changes accompany increases in mean slope and mean sand size in the same south-to-north direction. This reflects the glacial origin of the coarser sediment on Cape Cod, Rhode Island, and the Long Island beaches, in contrast to the local, reworked material on the New Jersey beaches.

The mean shoreline orientation ranges over 90°. The beaches on Cape Cod face the east-northeast; those on Rhode Island and Long Island face the south-southeast. Misquamicut Beach is partially sheltered by Block Island and, similar to the Long Island beaches, is sheltered from northeasterly winds by its orientation. The three New Jersey beaches face the southeast, with Atlantic City facing more toward the south than Long Beach Island or Ludlam Island.

3. Data Collection.

The 91 surveyed profile lines were located at previously established bench marks with known elevations. The landward end of the profile lines terminated most frequently in dunes or on boardwalks in developed areas or on cliffs, such as at Cape Cod. In the seaward direction, the surveys were intended to reach -2 feet MSL, but because of high water they did not always reach that far. Distance and elevation were determined by tape and level techniques, except for the New York District surveys where stadia

Table 2. Physical parameters of the seven localities.

Locality	Exposure	Tidal Range (ft)	Littoral materials		Beach characteristics
			Size	Composition[1]	
Cape Cod, Mass.	Faces NE., Atlantic Ocean, Gulf of Maine	7.6	Medium to coarse	Quartz, rock fragments, garnet	Narrow beach in front of cliffed shoreline of glacial sand, gravel, and cobbles. No houses on beach.
Misquamicut, R.I.	Faces S., partly sheltered	2.6	Medium	Quartz, rock fragments	Sandy with cobbles on west end. Sandy with high dunes on east end. Houses on beach.
Westhampton Beach, N.Y.	Faces S., open ocean	2.9	Medium to fine	Almost all quartz, small concentration of garnet	Sand beach with dunes. Houses on eastern and center sections. Groins and recent beach fill in center section.
Jones Beach, N.Y.	Faces S., open ocean, fetch from west restricted by New Jersey coast	3.6	Medium to fine	Almost all quartz	Sand beach. State Park. Few structures on beach. Low dunes.
Long Beach Island, N.J.	Faces SE., open ocean	4.1	Medium	Almost all quartz	Sand beach. Low dunes. Houses on beach. Numerous groins.
Atlantic City, N.J.	Faces SE., open ocean	4.1	Fine	Quartz	Wide sand beach. No houses seaward of boardwalk. Several piers, groins, and storm sewers cross beach.
Ludlam Island, N.J.	Faces SE., open ocean	4.1	Fine to very fine	Quartz with some peat	Sand beach with many relics of former wood groins, bulkheads, and houses. Few houses on beach, some low dunes eroding in places. Peat presently on beach face in eroding stretches.

[1]Almost all quartz, $\geq$ 96 percent; mostly quartz, 92 to 96 percent;quartz, 80 to 92 percent.

was used for distance on Westhampton Beach and Jones Beach. Distance was measured to the nearest whole foot and elevations were measured to the nearest tenth of a foot. The survey data were recorded in field notebooks, transferred to optical-scanning sheets, and sent to CERC for processing.

In addition to the instrument surveys, sand levels were surveyed at rows of pipes installed along two profiles at each locality (Urban and Galvin, 1969). Position and elevation of the pipes had been determined previously by instrument leveling techniques. Local volunteer observers recorded the sand level at the pipes on optical-scanner forms.

Poststorm inspection trips were made to each locality by CERC personnel in order to visually assess damage to the beaches and structures. Data collected on these visits included visual wave observations, pipe profile surveys, photos and sketches, as well as interviews with residents.

4. Data Processing.

Processing of the storm data is summarized in the flow chart in Figure 7. Profile survey data were converted to punched cards, edited, and machine plotted; positions of contours and area changes under the profiles were computed (see Section V)

V. BEACH SURVEY RESULTS BY LOCALITIES

This section presents a detailed discussion of the effects of the 17 December 1970 storm on each of the seven localities. The discussion for each locality is illustrated by a location map, prestorm and poststorm profiles, and a table listing changes at each profile line.

The map of each locality identifies the profile lines where data were collected, including the two pipe profile lines observed. All location maps are the same scale to aid comparisons between localities.

The prestorm and poststorm profiles are plotted at a 15:1 vertical exaggeration. The horizontal axes of these plots are distances in feet measured from an origin which is the intersection of the datum and the profile of the initial survey. The positive direction is seaward from the origin. The datum is nominally MSL, but in most cases it is actually the mean tide level (MTL) obtained by adding half the mean tide range to the known mean low water datum. (The actual difference between MSL and MTL is negligible for the purpose of this paper.) Dates are given in the legend of each plot for the prestorm and poststorm surveys and for the initial survey used to establish the origin. Where possible, results obtained from the pipe profiles are included.

The table accompanying each locality lists two classes of data: Horizontal change in position of the shoreline, and unit volume change at the profile line (Fig. 8). The horizontal change in position of the

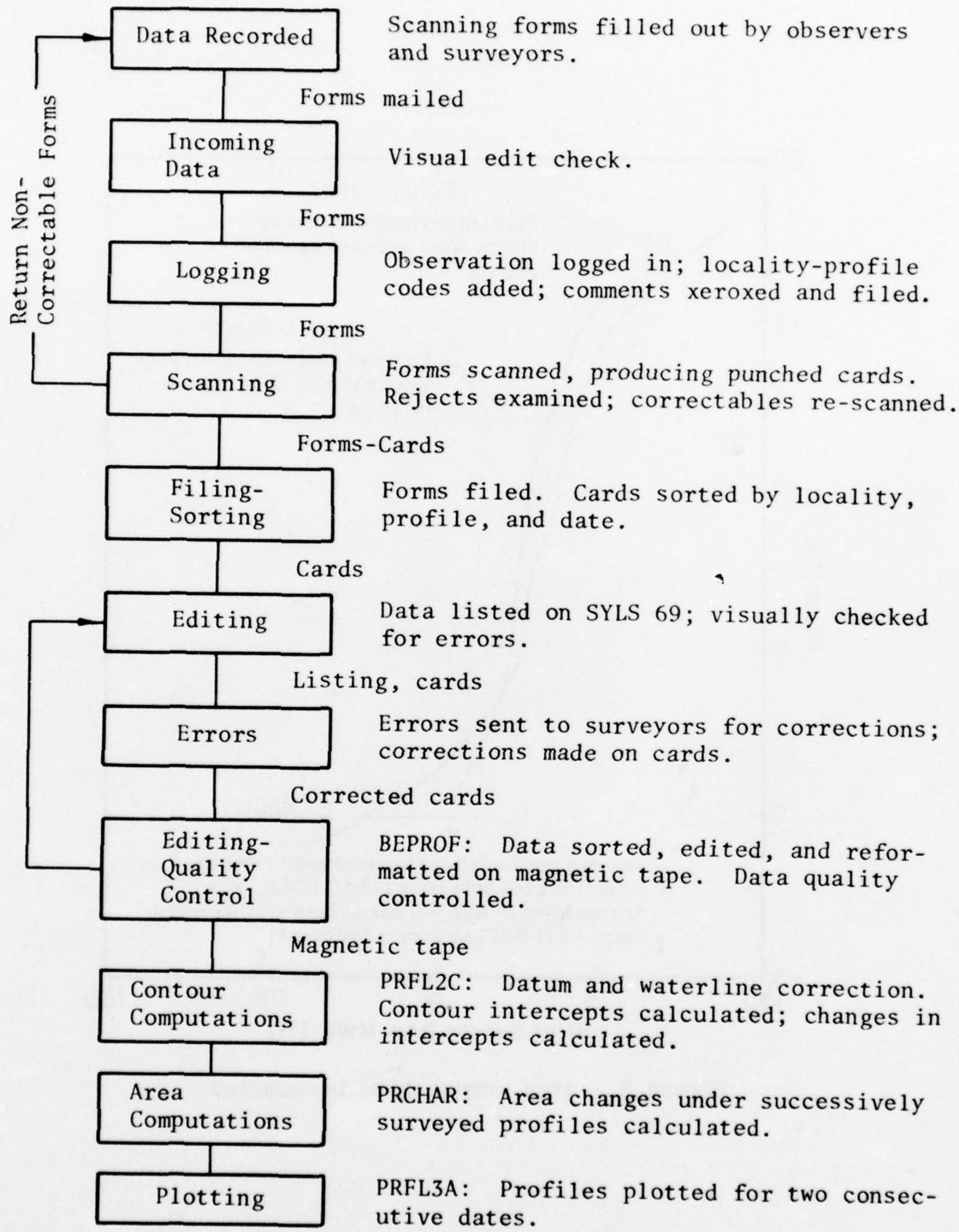


Figure 7. Flow chart for processing BEP survey data.

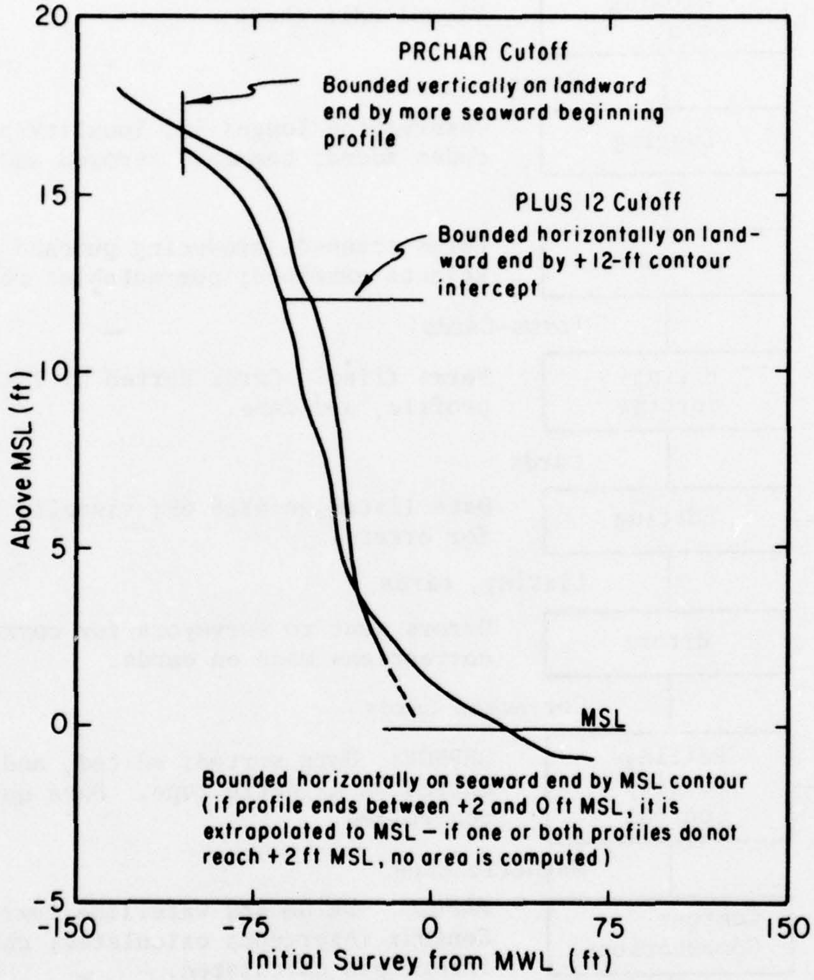


Figure 8. Area computation boundaries.

shoreline is the difference between the prestorm and poststorm positions of the MSL intercept on the profiles (poststorm distance minus prestorm distance). In those cases where MSL intersects the profile more than once (usually due to an accretionary ridge on the poststorm profile), the most seaward of the multiple intercepts is defined as the shoreline.

In the tables, unit volume change (in cubic yards per lineal foot of beach) is given in two ways: "PRCHAR" unit volume and "Plus 12" unit volume (Fig. 8). For most cases, PRCHAR unit volume is identical to Plus 12. Both unit volume changes are measured above MSL; i.e., above a horizontal line drawn landward from the most seaward MSL intercept. If either the prestorm or poststorm survey reaches 2 feet MSL but failed to cross MSL (perhaps because of high water at the time of the survey), that profile was extrapolated linearly to MSL. If either of the before-or-after profiles did not cross 2 feet MSL, unit volume was not computed. A positive area change indicates a net accretion on the profile line; negative area change indicates net erosion.

The distinction between PRCHAR and Plus 12 unit volume changes is in the limits on the landward side of the profile. The PRCHAR landward limit is defined by a vertical line intersecting both profiles and passing through the landward termination of at least one profile. (In most cases, both profiles terminate landward at the same point.) The Plus 12 landward limit is defined by drawing a horizontal line at +12 feet MSL elevation through both profiles, provided both profiles go above +12 feet MSL. If there is more than one Plus 12 intercept on a profile, the most seaward intercept is used. If either or both profiles fail to exceed +12 feet elevation, then the landward limit is the PRCHAR limit, modified if necessary so as not to include area above +12 feet elevation.

The choice of which landward limit to use becomes important on high profiles such as those at Cape Cod, Westhampton Beach, and Long Beach Island. The Plus 12 unit volume change differs from PRCHAR in not including the effect of changes at high elevations on cliffs, bluffs, or high dunes. Such changes include accretion of windblown sand and slumping of unstable slopes.

1. Cape Cod, Massachusetts.

The profile line locations are plotted in Figure 9, surveyed storm changes in Figure 10, and MSL contour and area changes in Table 3. A trend of decreasing erosion from north to south was noted which correlates with changes in beach morphology from the high (greater than 100 feet on profile 02), actively eroding scarps at Wellfleet, to the low accreting spit of Nauset Beach. Generally, erosion seemed to be greatest on the upper part of the profile (above +2 feet MSL) with deposition occurring below +1 foot elevation. The average net unit volume change above MSL between 10 and 18 December on the 10 Cape Cod profile lines was -5.5 cubic yards per foot or -8.1 cubic yards per foot if profile line 06 is eliminated because of the suspiciously large accretion on the face of the cliff.

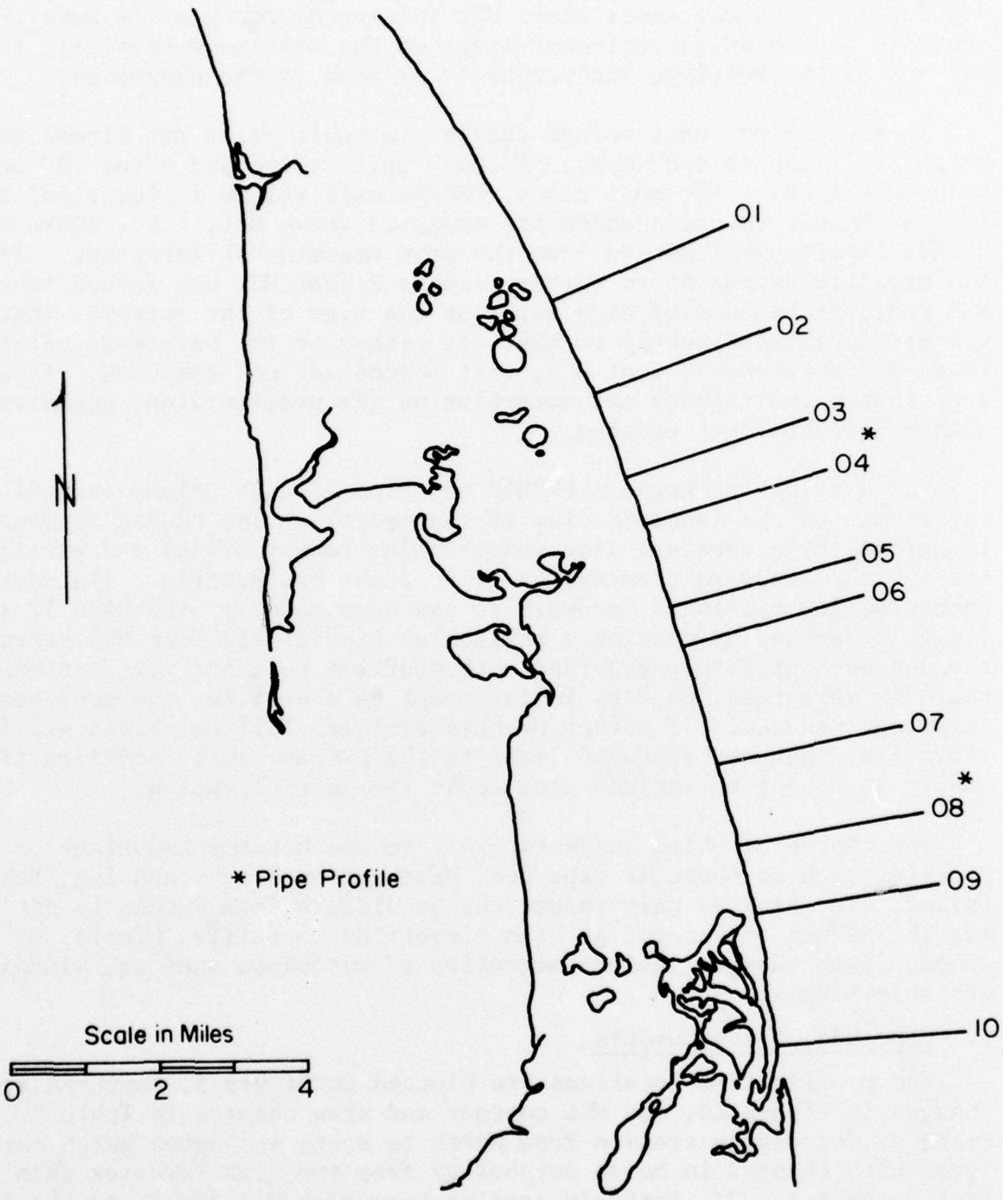


Figure 9. Profile line locations, Cape Cod, Massachusetts.

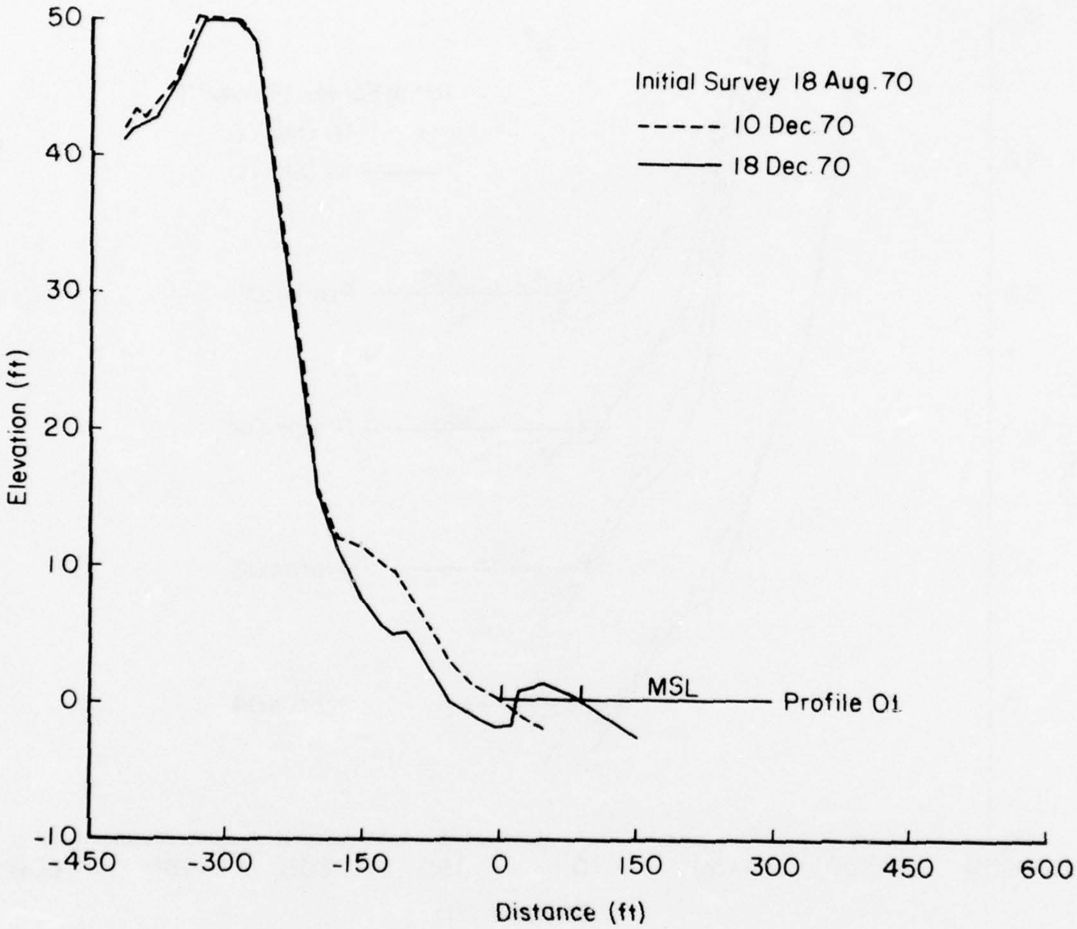


Figure 10. Prestorm and poststorm surveys at Cape Cod, Massachusetts.

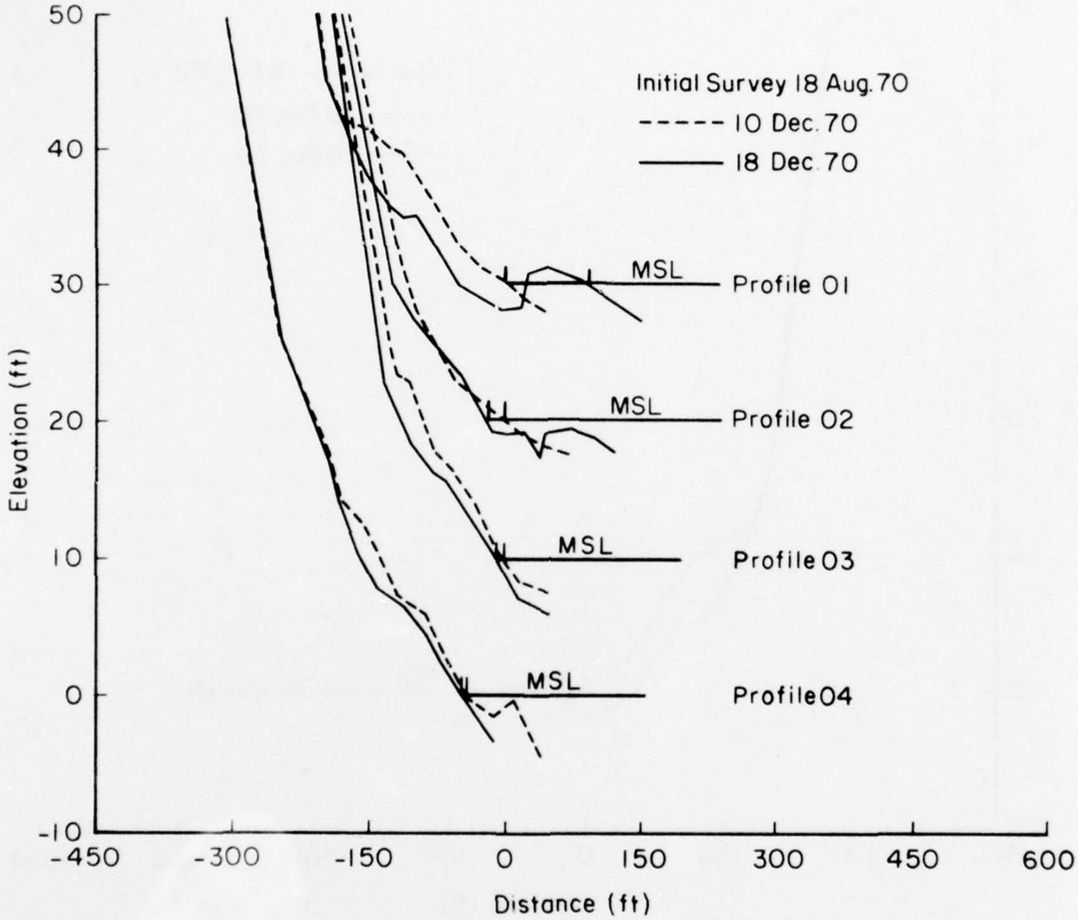


Figure 10. Prestorm and poststorm surveys at Cape Cod, Massachusetts.--Continued

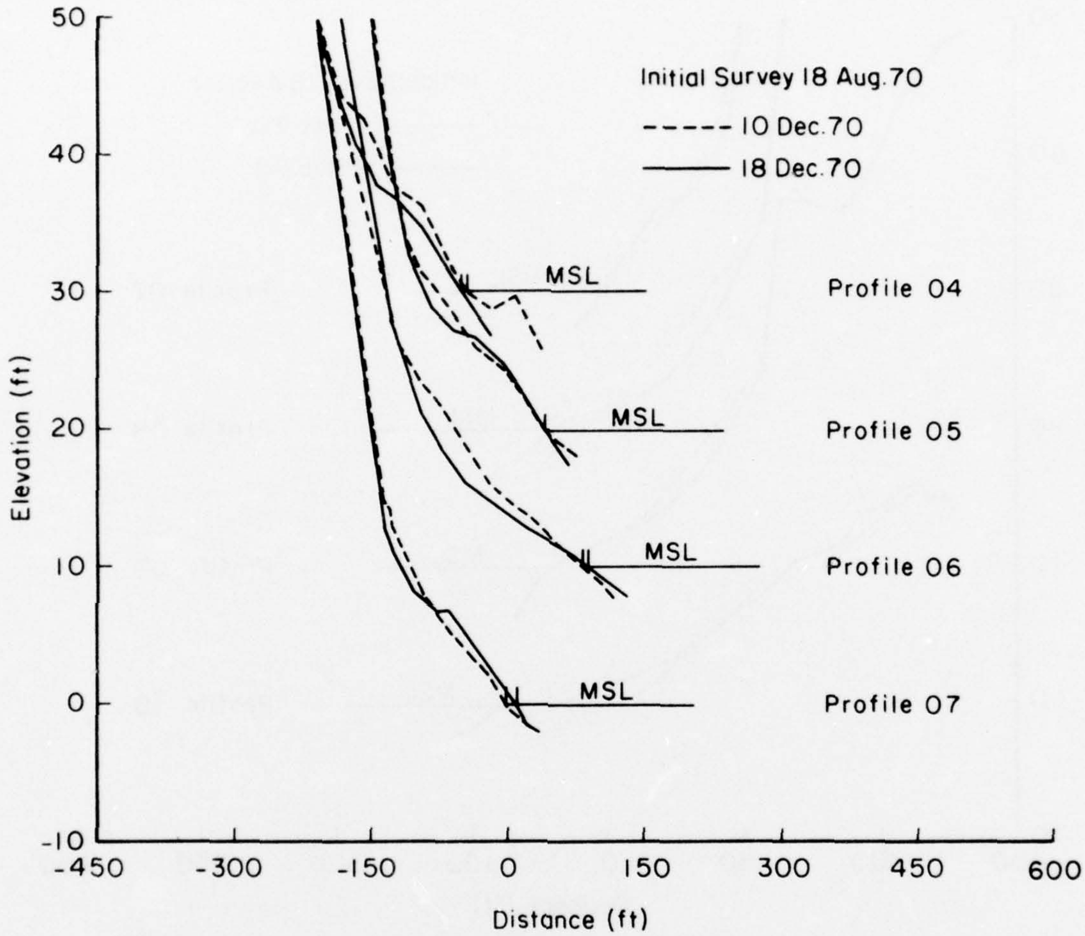


Figure 10. Prestorm and poststorm surveys at Cape Cod, Massachusetts.--Continued

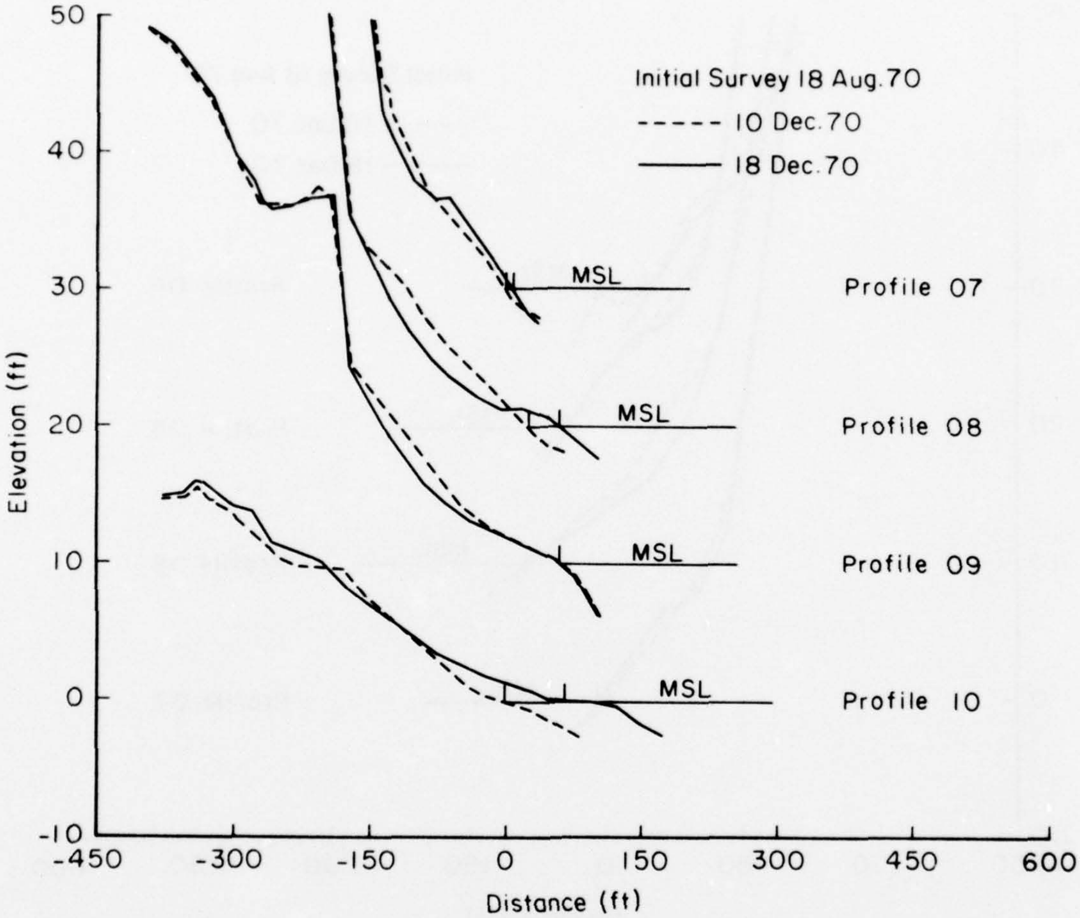


Figure 10. Prestorm and poststorm surveys at Cape Cod, Massachusetts.--Continued

Table 3. Shoreline and unit volume changes at Cape Cod for 17 December 1970 storm.

Profile line	MSL shoreline change (ft)	PRCHAR[1] unit volume (yd^3/ft)	Plus 12[1] unit volume (yd^3/ft)
01	86.7	-21.7	-17.7
02	-22.4	-12.9	-2.2
03	-7.9	-17.1	-5.2
04	-4.2	-8.4	-6.1
05	0.0	-2.6	-1.7
06	4.3	17.5	-9.0
07	6.9	-2.1	0.9
08	35.9	-10.2	-9.7
09	-2.7	-6.3	-6.5
10	66.7	8.8	5.6
Average	16.3	-5.5	-5.8

[1]See Figure 8 for definitions.

Pipe profiles were located along profile lines 04 and 08. At profile line 04, pipes 1 to 6 were read on both 16 and 18 December 1970. Maximum erosion at any one of the pipes was 4 feet, measured at pipe 4 where the sand level changed from 3.4 to -0.6 feet MSL. There was no accretion at any of the pipes.

At profile line 08, pipes 1 to 7 were read on both 16 and 18 December 1970. Maximum erosion at any one of the pipes was 2.5 feet, measured at pipe 2 where the sand level changed from 9.9 to 7.4 feet MSL. Maximum accretion at any one of the pipes was 0.5 foot, measured at pipe 3 where the sand level changed from 5.5 to 6.0 feet MSL.

2. Misquamicut Beach, Rhode Island.

Poststorm surveys at Misquamicut were not completed until 23 and 24 December, so the analysis of these data probably does not reflect maximum storm effects. A reconnaissance inspection of the profiles on 19 December indicated that the beach had already rebuilt significantly since the storm. Profile line locations are shown in Figure 11, prestorm and poststorm profiles in Figure 12, and MSL contour and area changes in Table 4. All profile lines showed a net loss from MSL to the 12-foot contour. Erosion was noted to be less severe on the east and west ends of the beach. This may be a result of protection afforded by Watch Hill Point on the west and Weekapaug Inlet to the east. Profile lines 01 and 02 are within 500

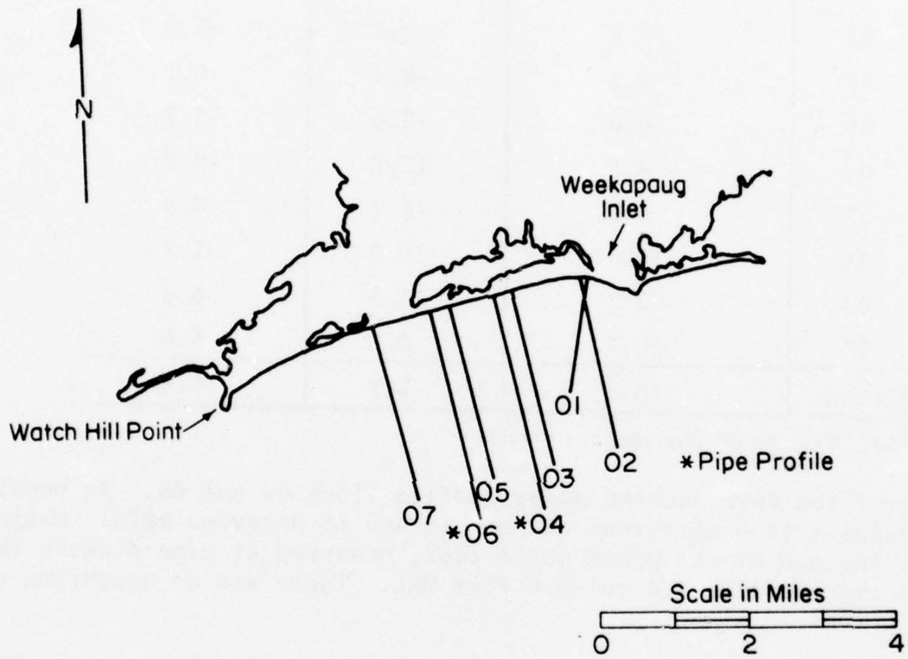


Figure 11. Profile line locations, Misquamicut, Rhode Island.

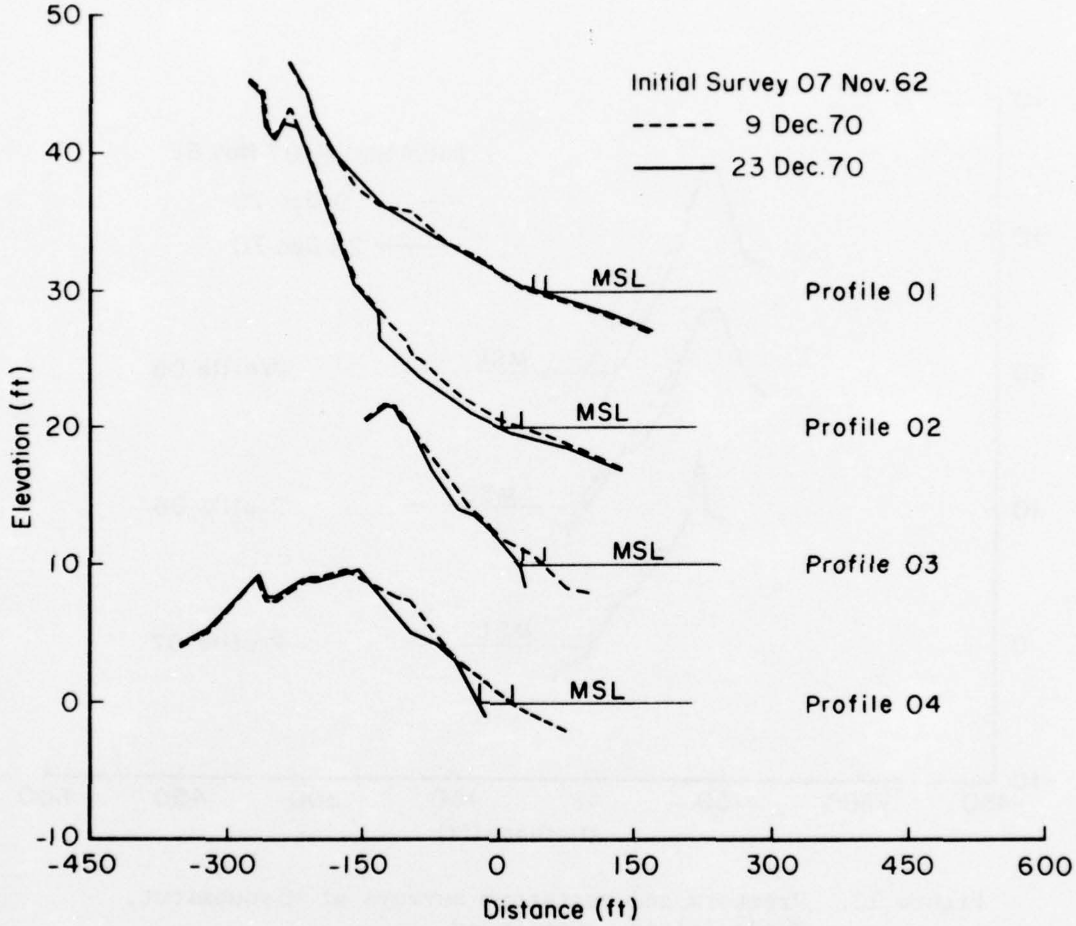


Figure 12. Prestorm and poststorm surveys at Misquamicut, Rhode Island.

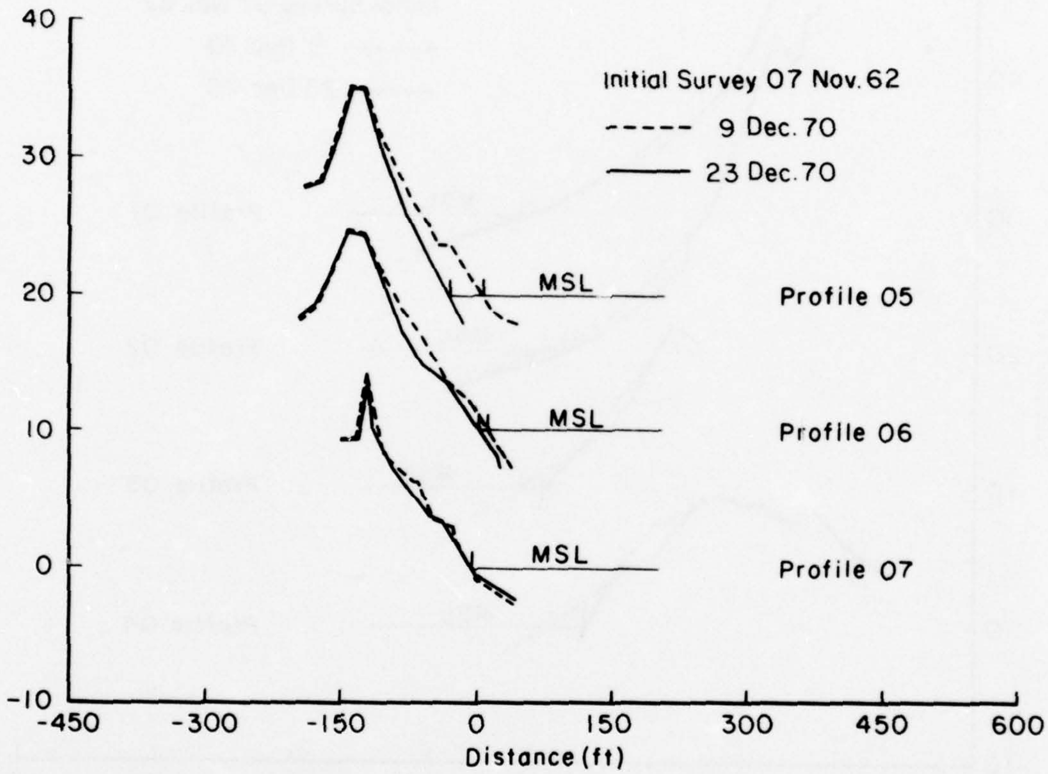


Figure 12. Prestorm and poststorm surveys at Misquamicut, Rhode Island.--Continued

feet of the west jetty at Weekapaug; profile line 07 is approximately 2 miles east of Watch Hill Point.

Table 4. Shoreline and unit volume changes at Misquamicut Beach for 17 December 1970 storm.

Profile line	MSL shoreline change (ft)	PRCHAR[1] unit volume (yd^3/ft)	Plus 12[1] unit volume (yd^3/ft)
01	4.2	-0.3	-0.5
02	-29.4	-6.0	-6.1
03	-26.3	-2.9	-2.9
04	-32.0	-4.6	-4.6
05	-38.2	-8.0	-8.0
06	-6.8	-4.2	-4.2
07	3.0	2.0	-1.9
Average	-17.9	-4.0	-4.0

[1]See Figure 8 for definitions.

There was minor accretion on the upper parts of profile lines 01 and 04. This may be due to eolian deposition in the dunes, or accumulation of slump material at the toe of the dune. Profile line 01 is an example of accumulation of slump material with erosion of the dune scarp and a comparable accretion at the toe. Accretion occurred below the 1-foot contour on profile lines 01 and 07 where surveys reached the -2-foot contour.

The average net volume change above MSL between 9 and 23 December on the seven Misquamicut Beach profiles was -4.0 cubic yards per foot. The MSL contour was displaced landward at all profile lines except 01 and 07.

Pipe profiles were located along profile lines 04 and 06. At profile line 04, pipes 1 to 5 were read on both 9 and 19 December 1970; pipes 3 and 4 were damaged, presumably by the storm. Maximum erosion at any one of the undamaged pipes was 2 feet, measured at pipe 2 where the sand level changed from 7.0 to 5.0 feet MSL. There was no accretion at any of the pipes.

At profile line 06, pipes 1, 2, and 5 were read on both 9 and 23 December 1970. Maximum erosion at any one of the pipes was 0.5 foot, measured at pipe 5 where the sand level changed from 0.5 to 0.0 foot MSL. There was no accretion at any of the pipes.

3. Westhampton Beach, New York.

Profile line locations are plotted in Figure 13, surveyed beach profiles in Figure 14, and MSL contour and area changes in Table 5. With the exception of profile lines 07, 08, and 11, all profile lines exhibited net erosion. Since prestorm surveys were done more than 2 weeks before the storm, profile changes were probably not entirely the result of the storm.

Table 5. *Shoreline and unit volume changes at Westhampton Beach for 17 December 1970 storm.*

Profile line	MSL shoreline change (ft)	PRCHAR[1] unit volume (yd^3/ft)	Plus 12[1] unit volume (yd^3/ft)
01	14.1	-3.4	-3.4
02	-12.4	-8.0	-8.0
03	-12.2	-1.7	-1.6
04	17.9	-16.9	-16.9
05	-63.0	-1.3	-6.2
06	-17.2	-8.6	-8.6
07	----[2]	7.1	7.1
08	17.9	3.9	4.6
09	-----	-4.9	-5.0
10	30.0	-12.5	-13.0
11	52.5	1.0	0.8
Average	3.1	-4.1	-4.6

[1]See Figure 8 for definitions.

[2]Poststorm survey did not reach MSL.

In general, the greatest erosion on the Westhampton profile lines was observed above the 6-foot contour; less erosion or accretion occurred on the lower profile. An exception was profile line 03 which showed minor accretion at the 6- to 4-foot contours, with erosion occurring on both the upper and lower parts of the profile.

Profile lines 06 to 09 are within a field of 15 groins and an associated artificial beach-fill project, which was completed in November 1970. Profile line 05, which is about 0.3 mile east of the easternmost groin, showed two sections of maximum erosion--between the 8- and 6-foot contours and between the 1-foot and MSL contours. Profile line 06, which is located midway between two groins, eroded between the 12-foot and MSL contours, with the greatest erosion occurring between the 8- and 6-foot contours.

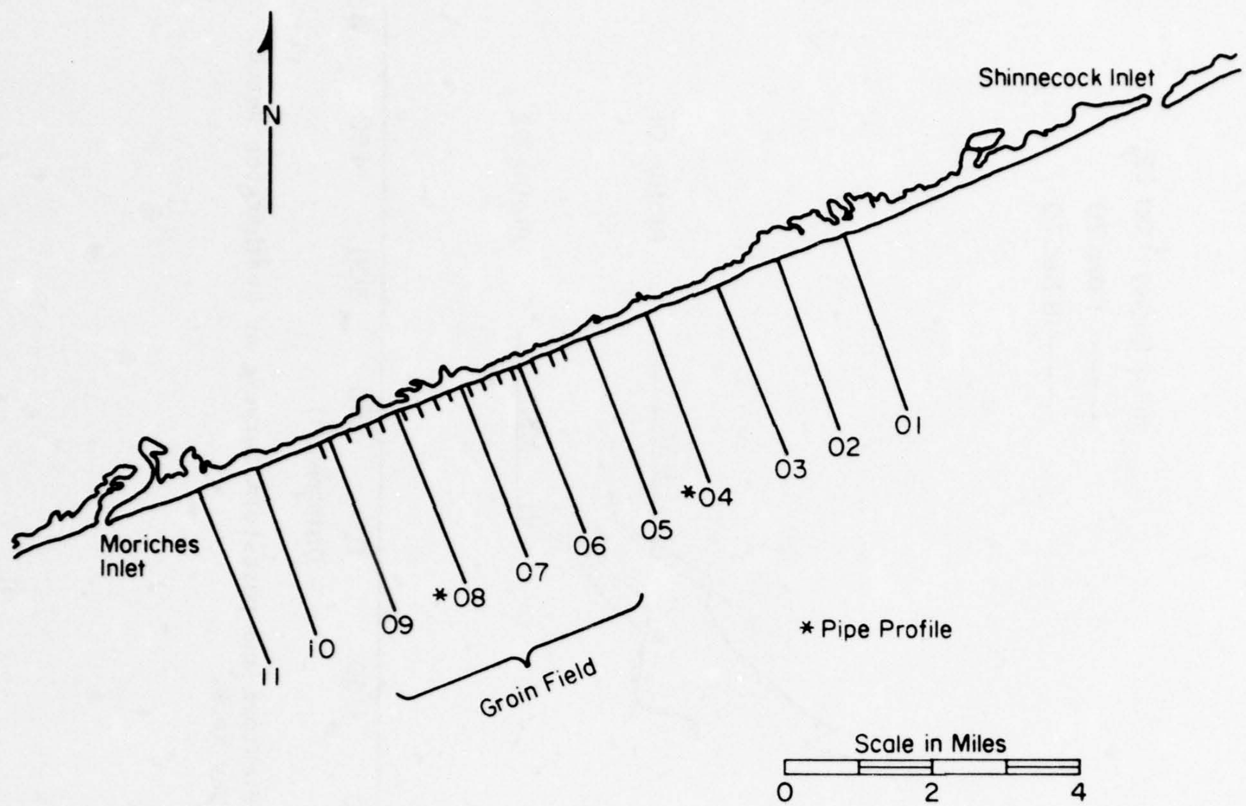


Figure 13. Profile line locations, Westhampton Beach, New York.

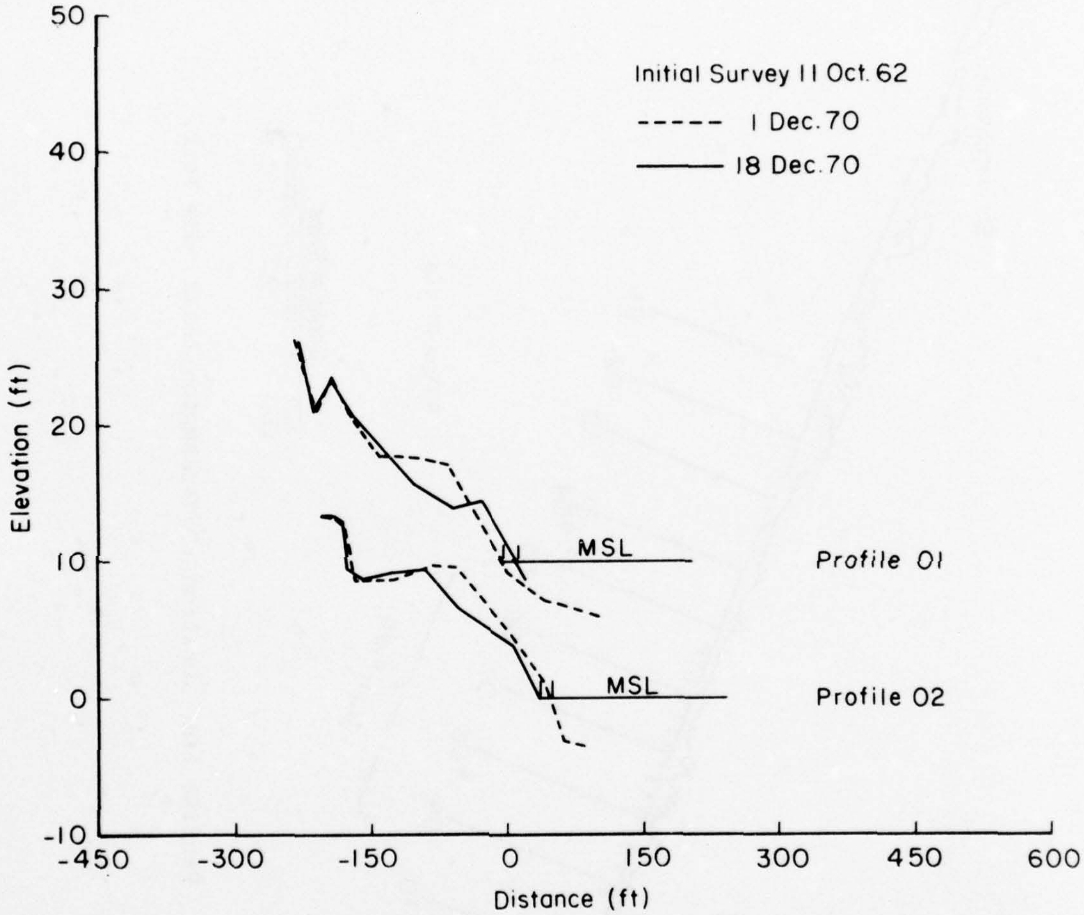


Figure 14. Prestorm and poststorm surveys at Westhampton Beach, New York.

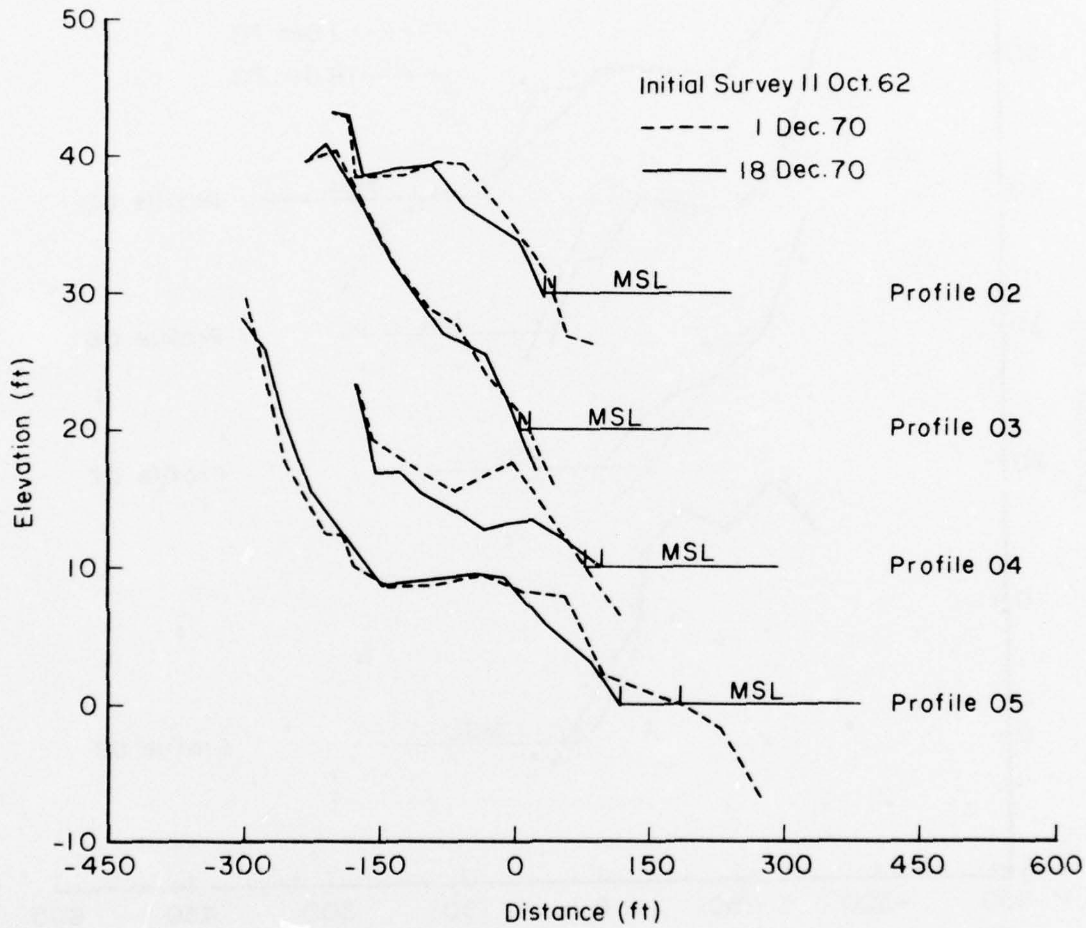


Figure 14. Prestorm and poststorm surveys at Westhampton Beach, New York.--Continued

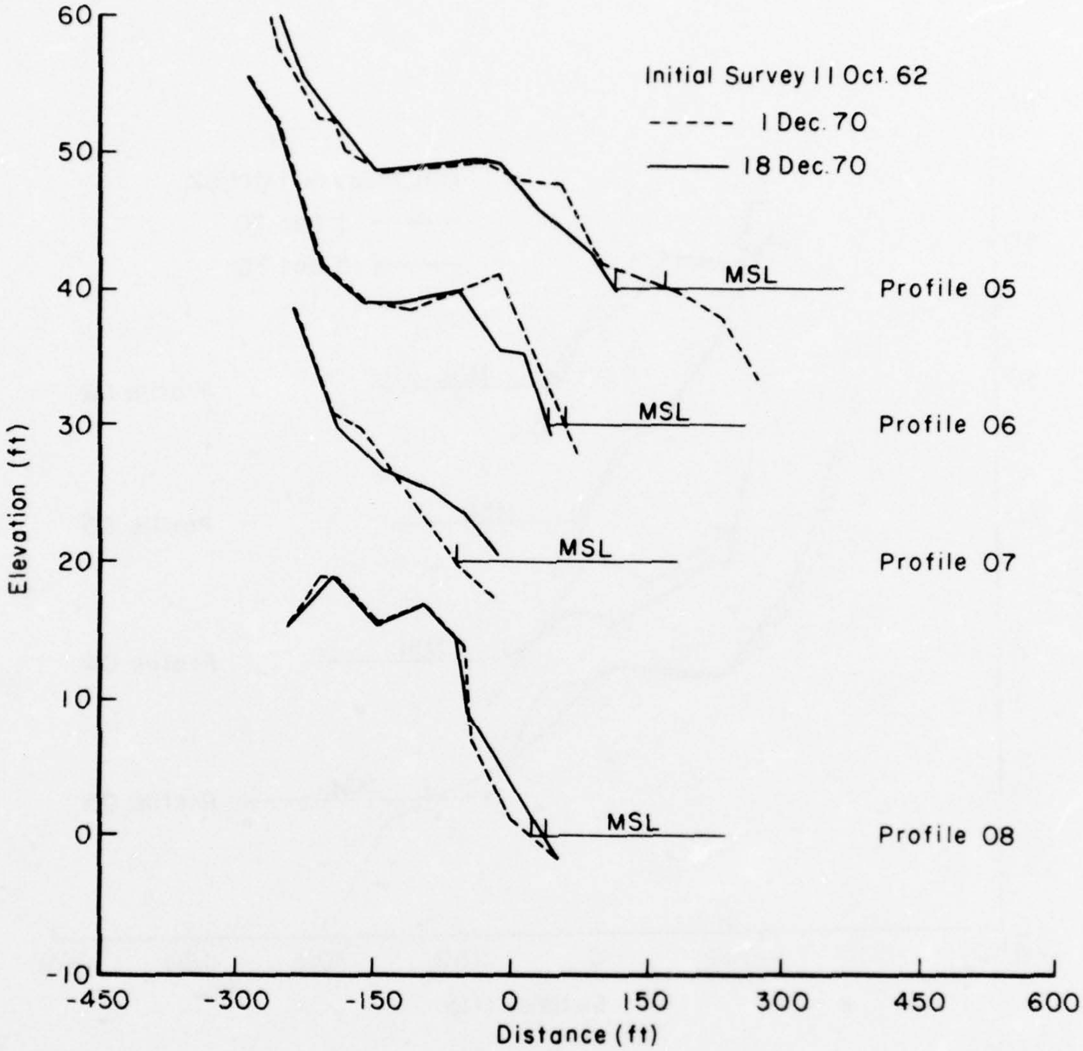


Figure 14. Prestorm and poststorm surveys at Westhampton Beach, New York.--Continued

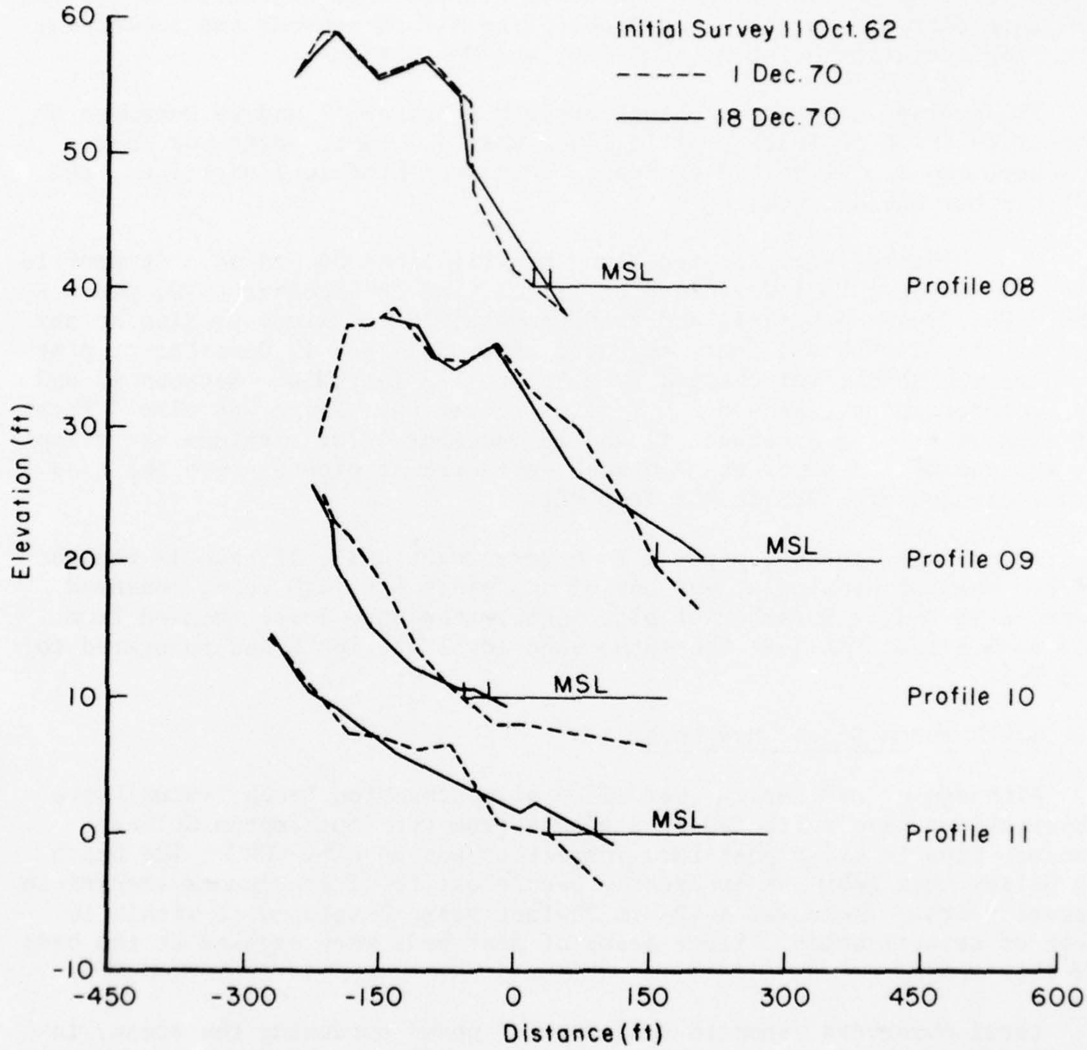


Figure 14. Prestorm and poststorm surveys at Westhampton Beach, New York.--Continued

Profile line 07, located 280 feet west of a groin, showed some erosion at the 11- to 8-foot contours, with accretion seaward to the -1-foot contour. Profile line 08, which is located 240 feet west of a groin, showed minor erosion at the 14- to 9-foot contours, with accretion seaward of the 9-foot contour to the -2-foot contour. Profile line 09, which is located 360 feet east of a groin, eroded above the 4-foot contour and showed increasing accretion between the 3-foot and MSL contours.

The average net volume change above MSL between 1 and 18 December on the 11 Westhampton Beach profile lines was -4.1 cubic yards per foot. However, the shoreline had eroded on only four profile lines; i.e., the MSL contour moved landward.

Pipe profiles were located along profile lines 04 and 08. At profile line 04, pipes 1 to 4 were read on 11, 17, and 18 December 1970; pipes 5 and 6 were read on both 11 and 18 December 1970. Maximum erosion at any one of the pipes was 4 feet, measured between 11 and 17 December at pipe 4 where the sand level changed from 5.8 to 1.8 feet MSL. Between 17 and 18 December, pipe 4 showed 2.5 feet of accretion. There was also 4 feet of erosion at pipe 3 between 11 and 18 December 1970. Maximum accretion at any one of the pipes was 4.0 feet, measured at pipe 6 where the sand level changed from 0.5 to 4.5 feet MSL.

At profile line 08, pipes 1 to 6 were read on 11, 17, and 18 December 1970. Maximum erosion at any one of the pipes was -4.0 feet, measured between 11 and 17 December at pipe 5 where the sand level changed from 9.3 to 5.3 feet MSL. By the 18th, sand level at pipe 5 had recovered to 8.3 feet.

4. Southampton Beach, New York.

Although no BEP surveys were made at Southampton Beach, visual wave observations were collected by students from the Southampton College Geology Department; a poststorm inspection was made by CERC. The beach at Halsey Neck Lane has apparently been the site of continuous erosion in recent years. There was a 10- to 20-foot scarp developed to within 10 feet of several homes. Large areas of peat beds were exposed at the base of this scarp.

Local observers reported that several ponds bordering the ocean, including Mecox Bay, had broken through the barrier beach to the ocean. At least one additional washover had occurred approximately 2.3 miles east of Shinnecock Inlet. Several of these areas were still flooded on 18 December, but had not remained open.

5. Jones Beach, New York.

Profile lines 10 to 18 were surveyed on 19 December (2 days after the storm), and profile lines 02, 03, 04, 07, 08, and 09 were surveyed on 20 December. (Profile lines 01, 05, and 06 were not regularly surveyed in

this study.) Because of the delay in the poststorm survey and the rapid recovery observed at Westhampton Beach pipe profiles, it is probable that the poststorm survey is not an accurate picture of maximum erosion at Jones Beach. Profile line locations are shown in Figure 15, surveyed beach profiles in Figure 16, and MSL contour and area changes in Table 6. Maximum erosion occurred at profile line 04. Profile lines 08 and 09 showed the only net accretion. Maximum erosion occurred between the 9- and 4-foot contours on all profile lines. Either accretion or less severe erosion, occurred between the 3- and 1-foot contours. Nine of the 16 poststorm profiles indicated additional erosion below the 1-foot contour.

Table 6. Shoreline and unit volume changes at Jones Beach for 17 December 1970 storm.

Profile line	MSL shoreline change (ft)	PRCHAR[1] unit volume (yd^3/ft)	Plus 12[1] unit volume (yd^3/ft)
02	-11.0	-4.0	-4.0
03	-25.1	-4.0	-4.0
04	-33.2	-19.4	-18.9
07	-26.6	-9.8	-10.4
08	-5.3	1.4	1.2
09	29.3	2.6	2.1
10	-2.5	-8.7	-8.6
11	-10.2	-2.8	-2.1
12	-28.6	-9.4	-9.4
13	-4.0	-5.6	-5.6
14	-19.4	-14.5	-14.5
15	-5.3	-11.7	-11.7
16	19.0	-7.5	-7.5
17	----[2]	-16.5	-16.5
18	0.4	-1.2	-1.2
Average	-8.8	-7.4	-7.4

[1]See Figure 8 for definitions.

[2]Poststorm survey did not reach MSL.

Profile line 02, the eastern limit of the Jones Beach survey, is located approximately 1 mile west of the dike at Fire Island Inlet. There was slight accretion at the 4-foot contour, with erosion occurring along the rest of the profile.

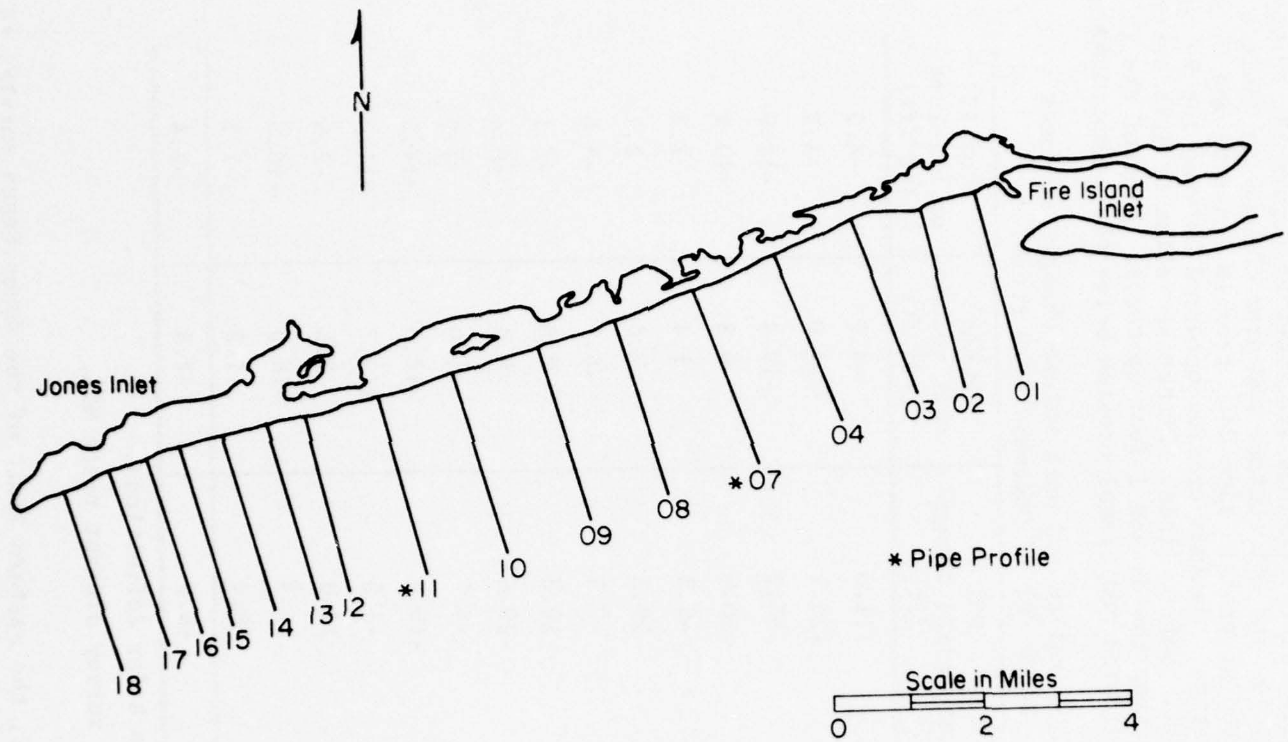


Figure 15. Profile line locations, Jones Beach, New York.

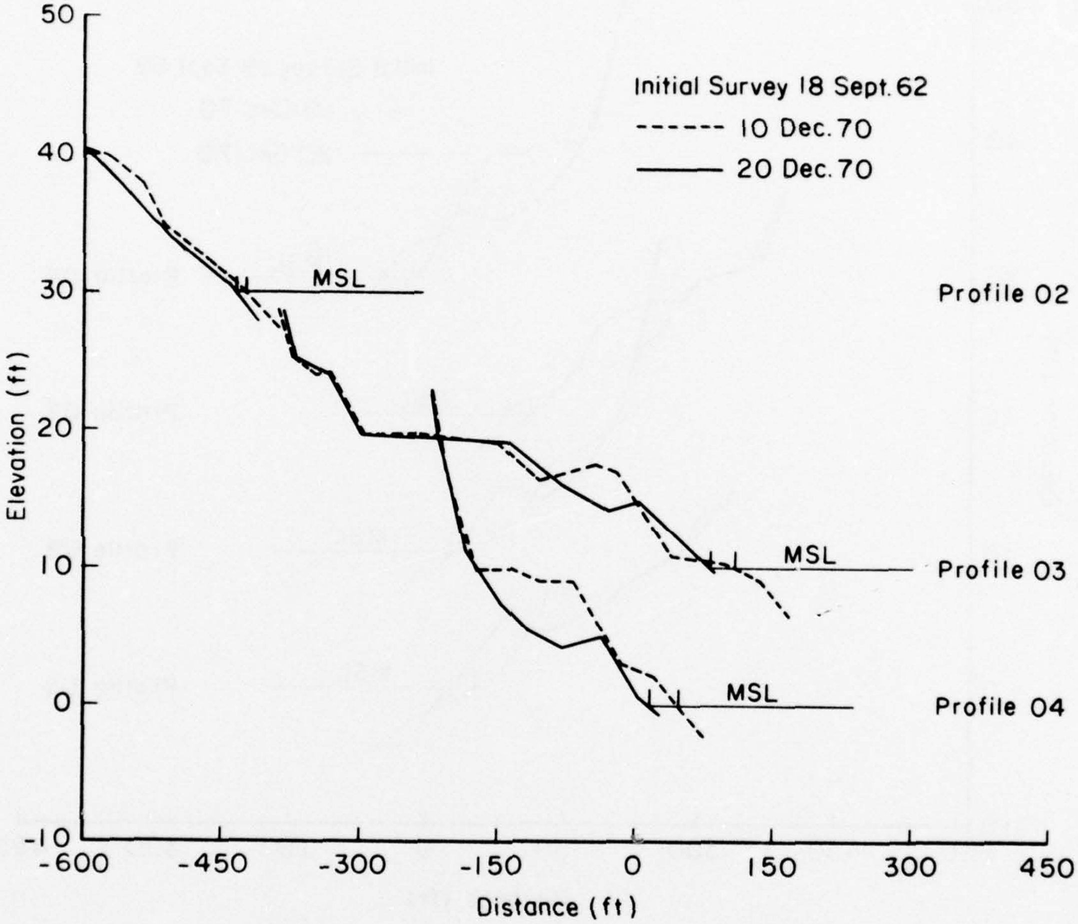


Figure 16. Prestorm and poststorm surveys at Jones Beach, New York.

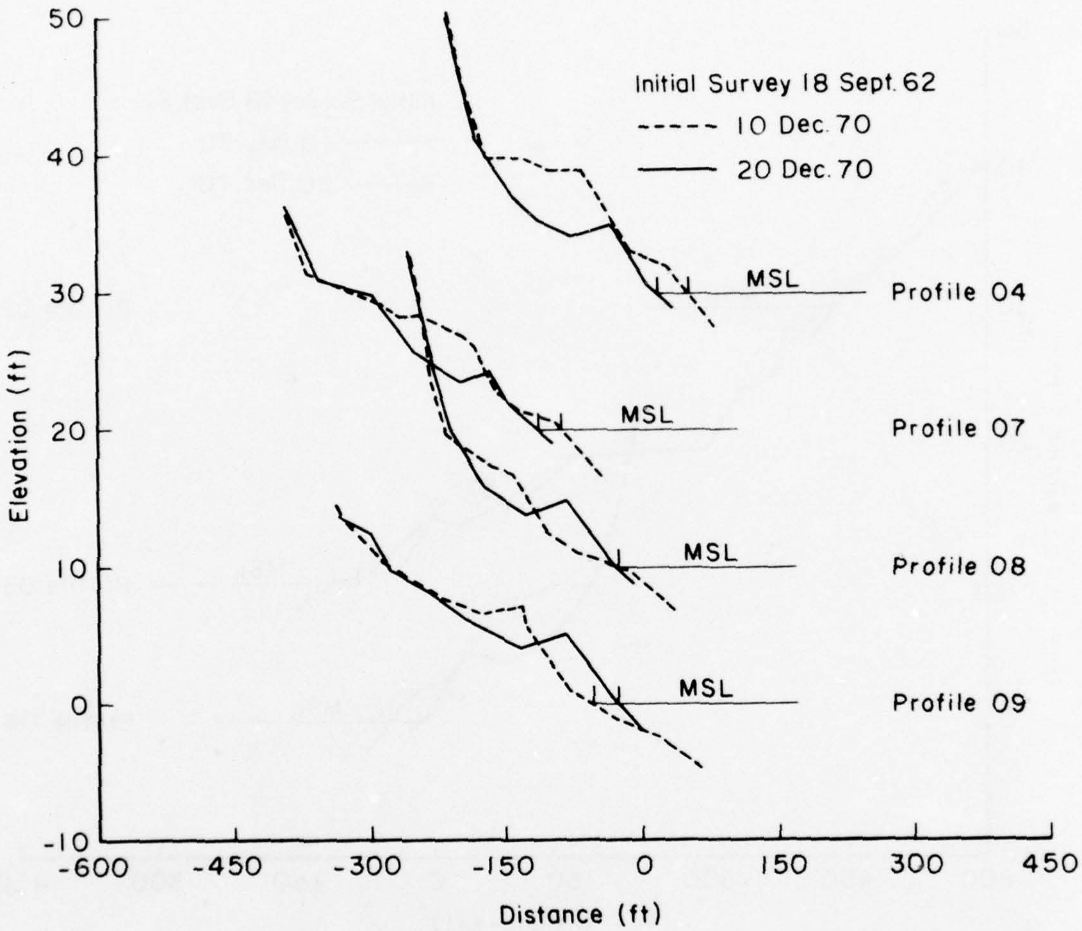


Figure 16. Prestorm and poststorm surveys at Jones Beach, New York.--Continued

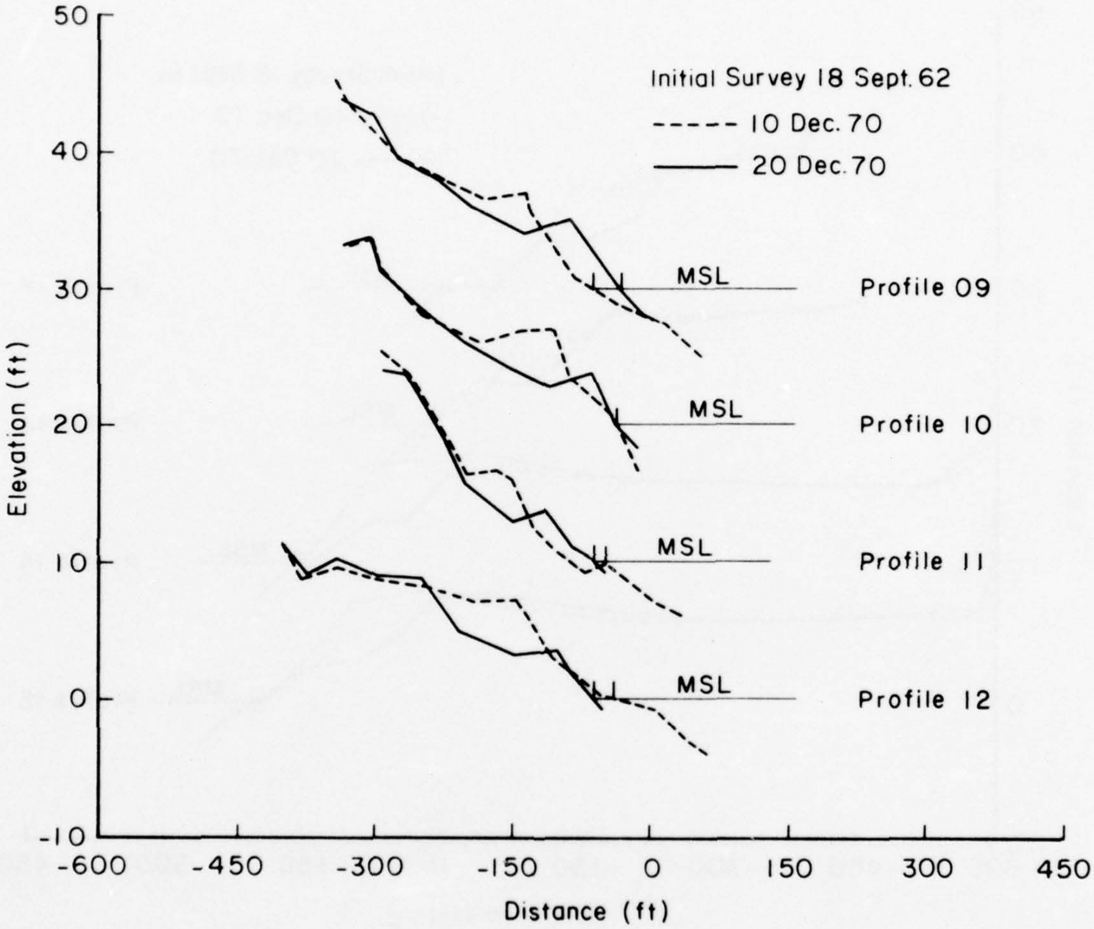


Figure 16. Prestorm and poststorm surveys at Jones Beach, New York.--Continued

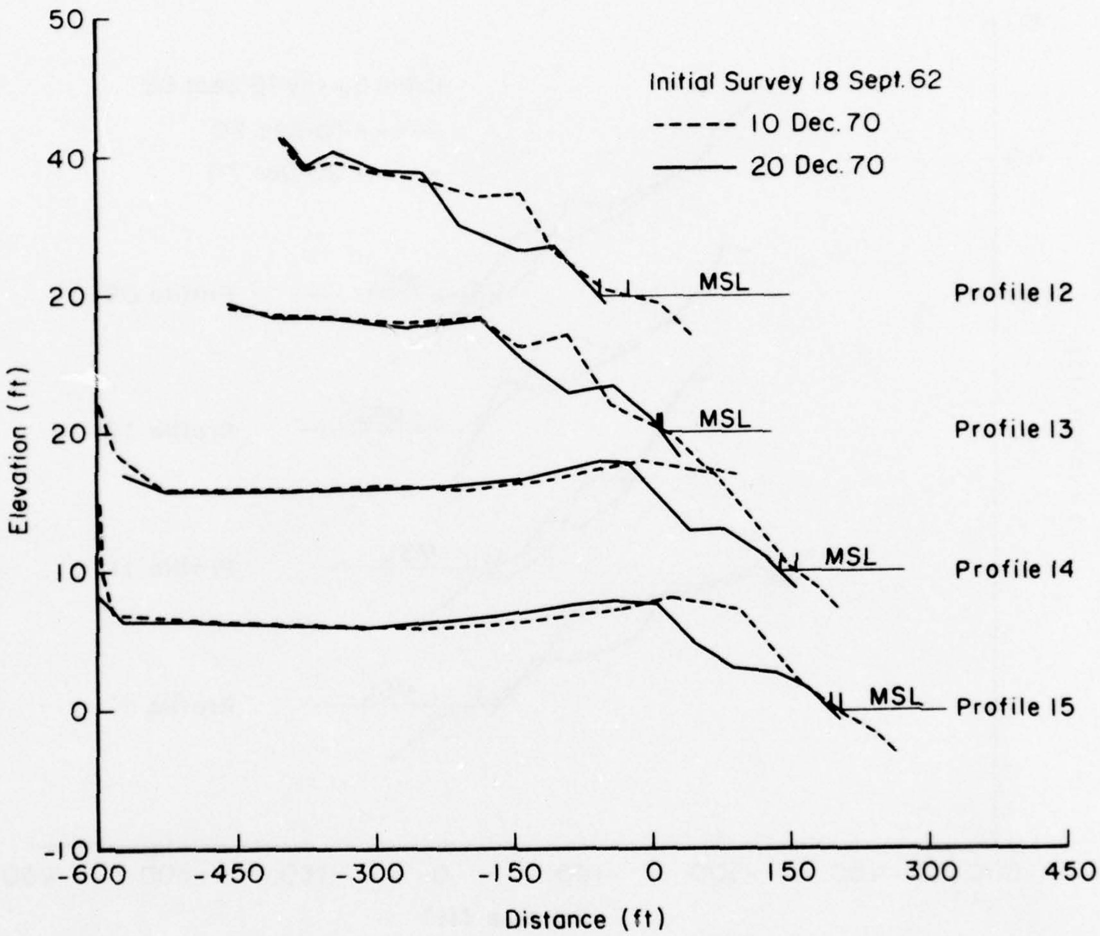


Figure 16. Prestorm and poststorm surveys at Jones Beach, New York.--Continued

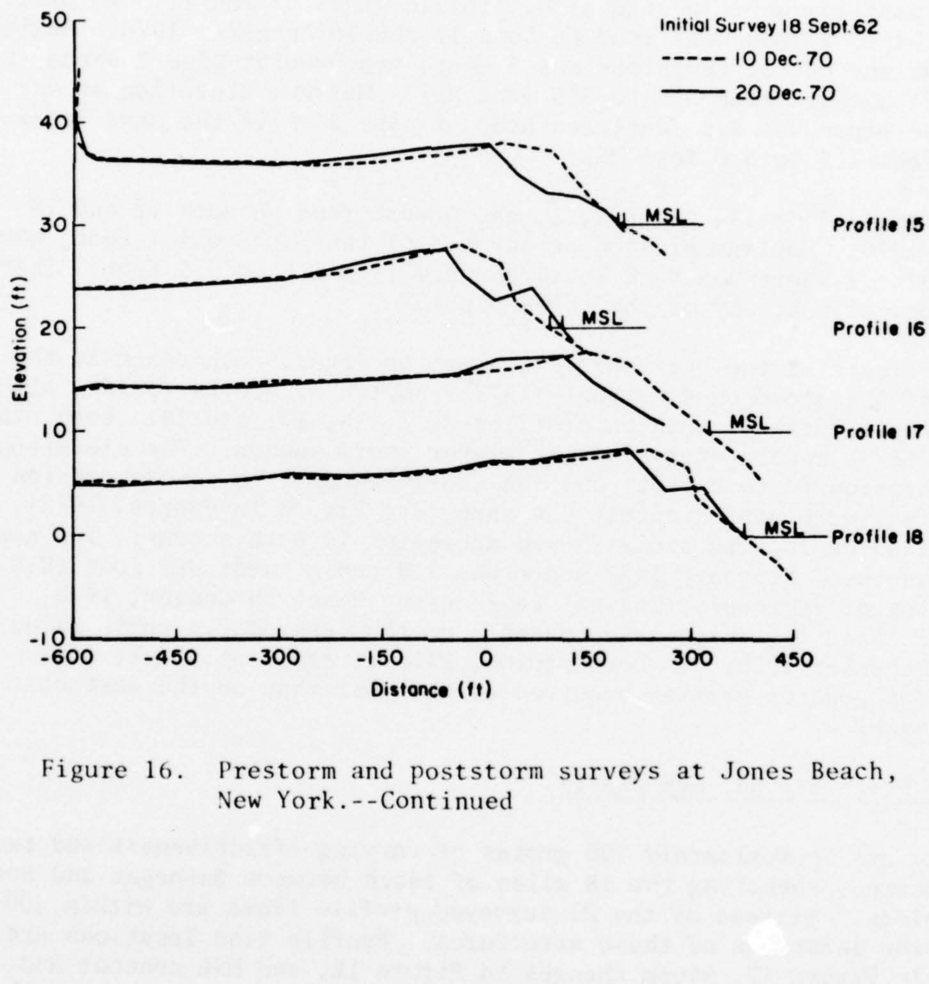


Figure 16. Prestorm and poststorm surveys at Jones Beach, New York.--Continued

Profile line 18, on the west end of Jones Beach, is located approximately 1 mile east (updrift) of the Jones Inlet jetty where the beach has been accreting since placement of the jetty. The profile line showed a slight net erosion from the storm, although accretion occurred between the 4-foot and MSL contours and from the 8- to 7-foot contours.

The average net unit volume change above MSL on the 15 Jones Beach profiles was -7.4 cubic yards per foot.

Pipe profiles were located along profile lines 07 and 11. At profile line 07, pipes 1 to 5 were read on both 12 and 18 December 1970. Maximum erosion at any one of the pipes was 3 feet, measured at pipe 3 where the sand level changed from 8.5 to 5.5 feet MSL. Maximum accretion at any one of the pipes was 1.5 feet, measured at pipe 4 where the sand level changed from 1.5 to 3.0 feet MSL.

At profile line 11, pipes 1, 2, and 3 were read on both 12 and 18 December 1970. Maximum erosion at any one of the pipes was 1 foot, measured at pipe 2 where the sand level changed from 6.5 to 5.5 feet. There was no accretion at any of the three pipes.

The effects of the December 1970 storm on Jones Beach resemble the effects of the storm on 4 February 1972 reported by Everts (1973), although Everts' report deletes data on profiles 2, 3, 16, 17, and 18. Both storms were the first severe storms of the winter storm season. The elevation of maximum erosion (4 to 9 feet) and the accretion or less severe erosion below 3 feet were approximately the same (see Fig. 5 in Everts, 1973). Profile line 08 in this study showed accretion in both storms. The average erosion in the 4 February 1972 storm was 9.9 cubic yards per foot (U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1975, p. 4-73 in Vol. 1), which is comparable to the loss of 7.4 cubic yards per foot in December 1970. In both storms, MSL retreated at almost every profile and greater erosion occurred on the west than on the east half of the beach.

6. Long Beach Island, New Jersey.

There are approximately 100 groins of varying effectiveness and two major jetties protecting the 18 miles of beach between Barnegat and Beach Haven Inlets. Sixteen of the 21 surveyed profile lines are within 400 feet of the least one of these structures. Profile line locations are plotted in Figure 17, storm changes in Figure 18, and MSL contour and area changes in Table 7. Most of the profiles showed net erosion. The exceptions were profile lines 03, 04, 07, 10, and 19. The prestorm survey at profile line 12 was judged unreliable so changes were not computed.

Erosion generally increased from north to south, with maximum erosion occurring at profile line 18. Maximum erosion was observed between the 8- and 5-foot contours on 16 of the profile lines. Profile line 03 had

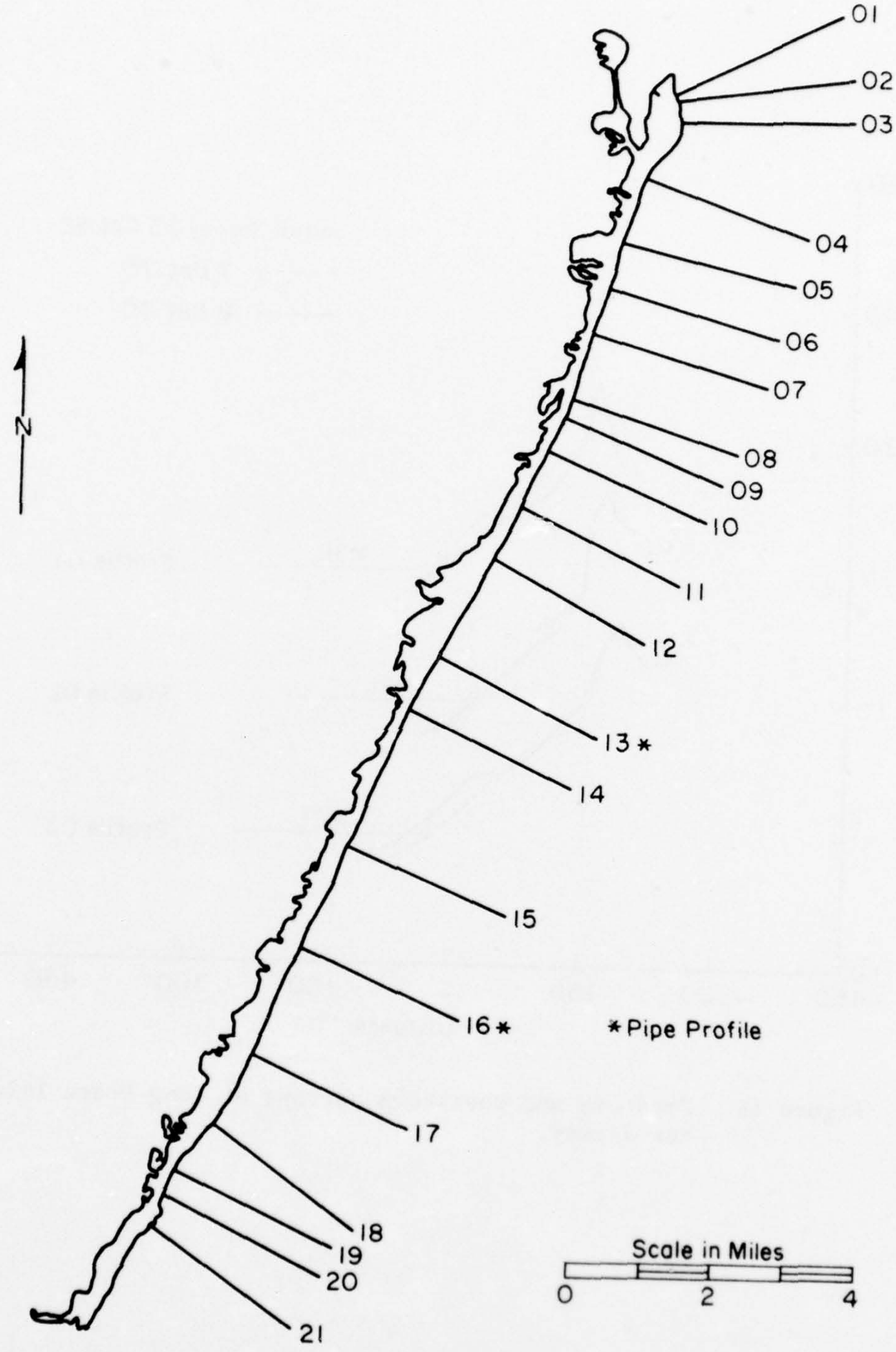


Figure 17. Profile line locations, Long Beach Island, New Jersey.

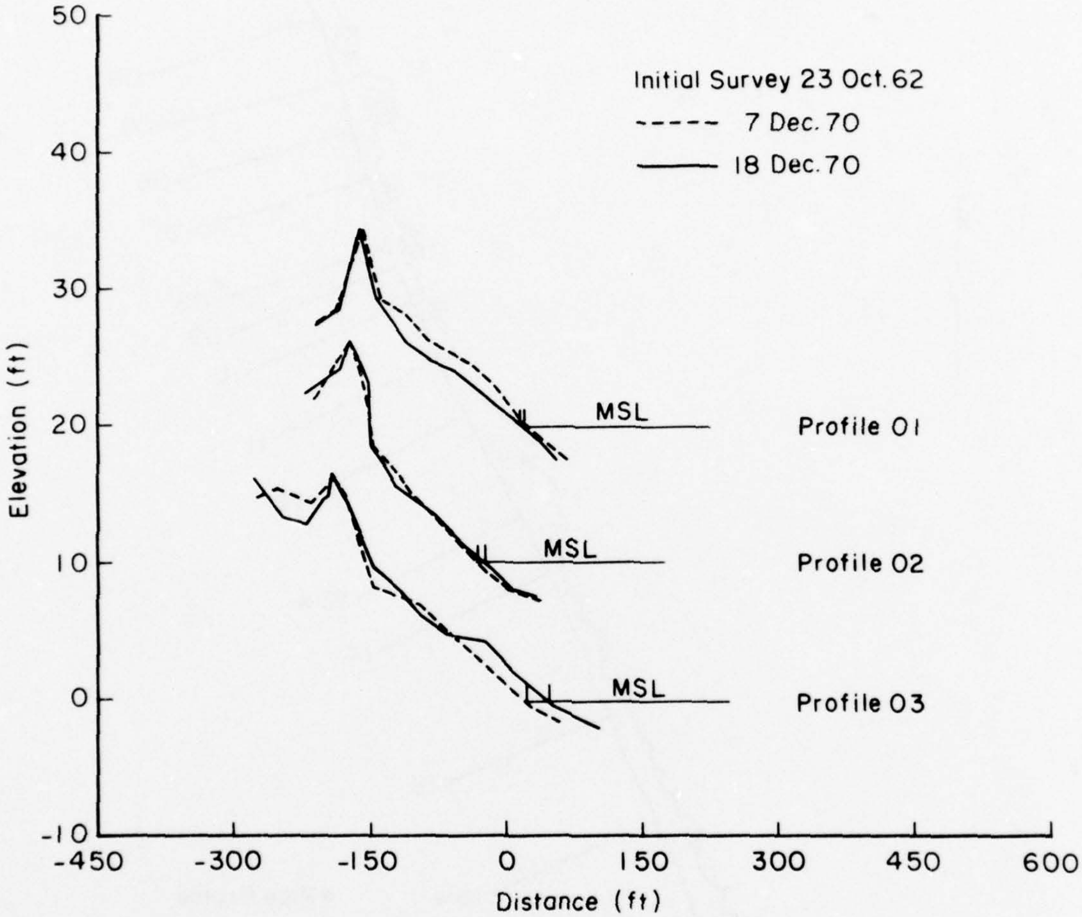


Figure 18. Prestorm and poststorm surveys at Long Beach Island, New Jersey.

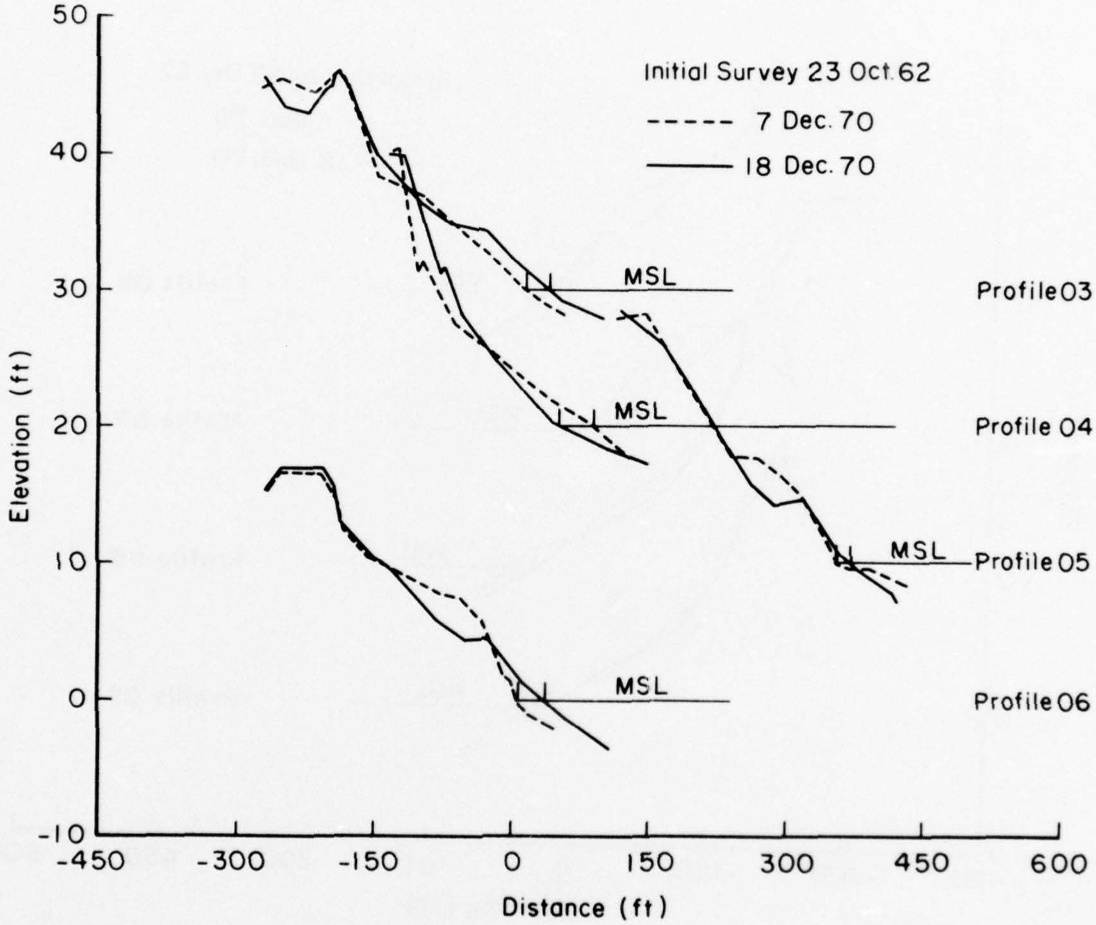


Figure 18. Prestorm and poststorm surveys at Long Beach Island, New Jersey.--Continued

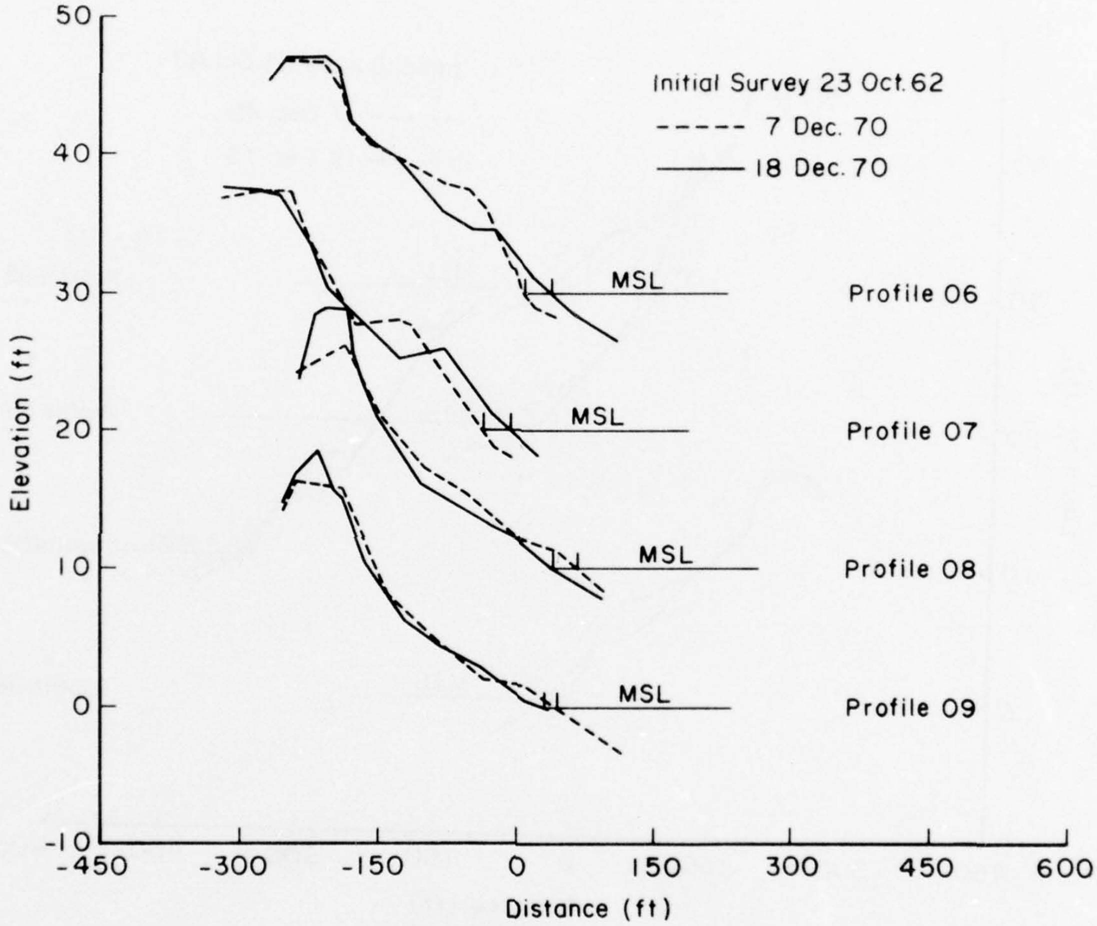


Figure 18. Prestorm and poststorm surveys at Long Beach Island, New Jersey.--Continued

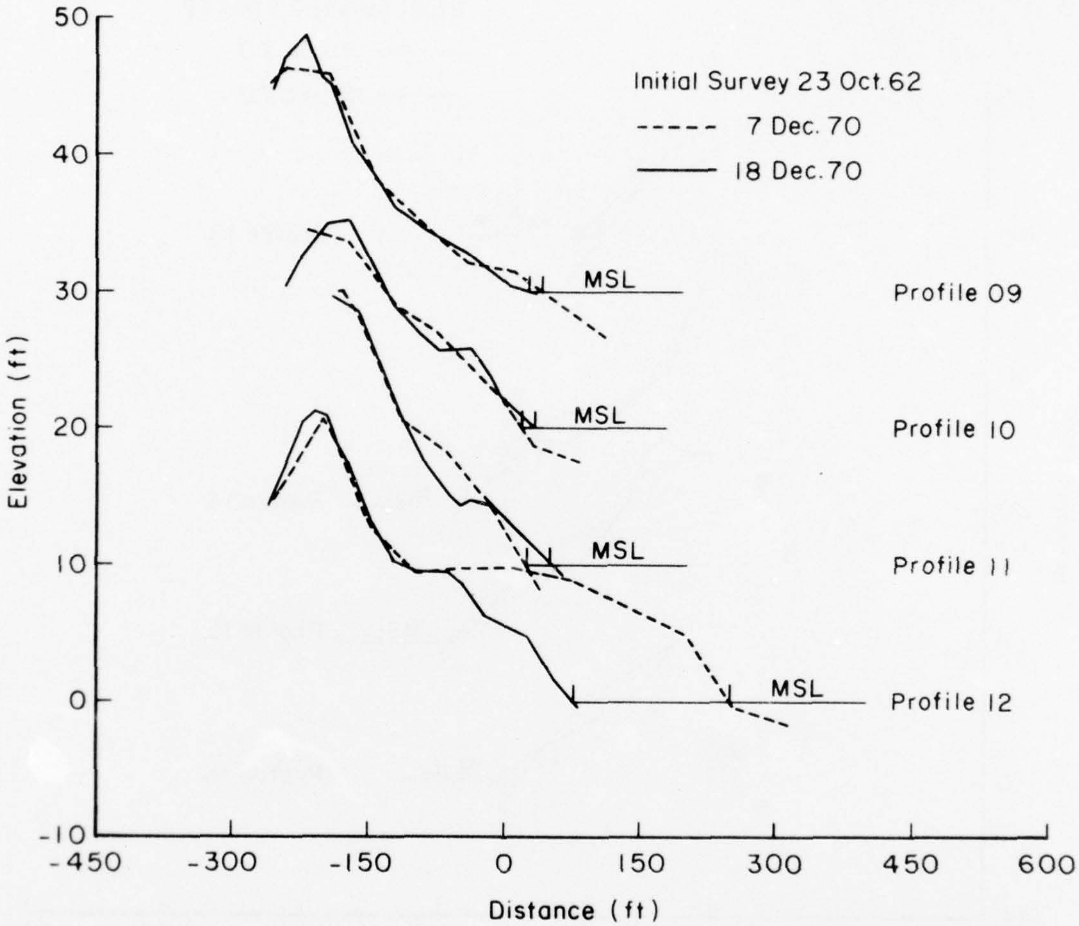


Figure 18. Prestorm and poststorm surveys at Long Beach Island, New Jersey.--Continued

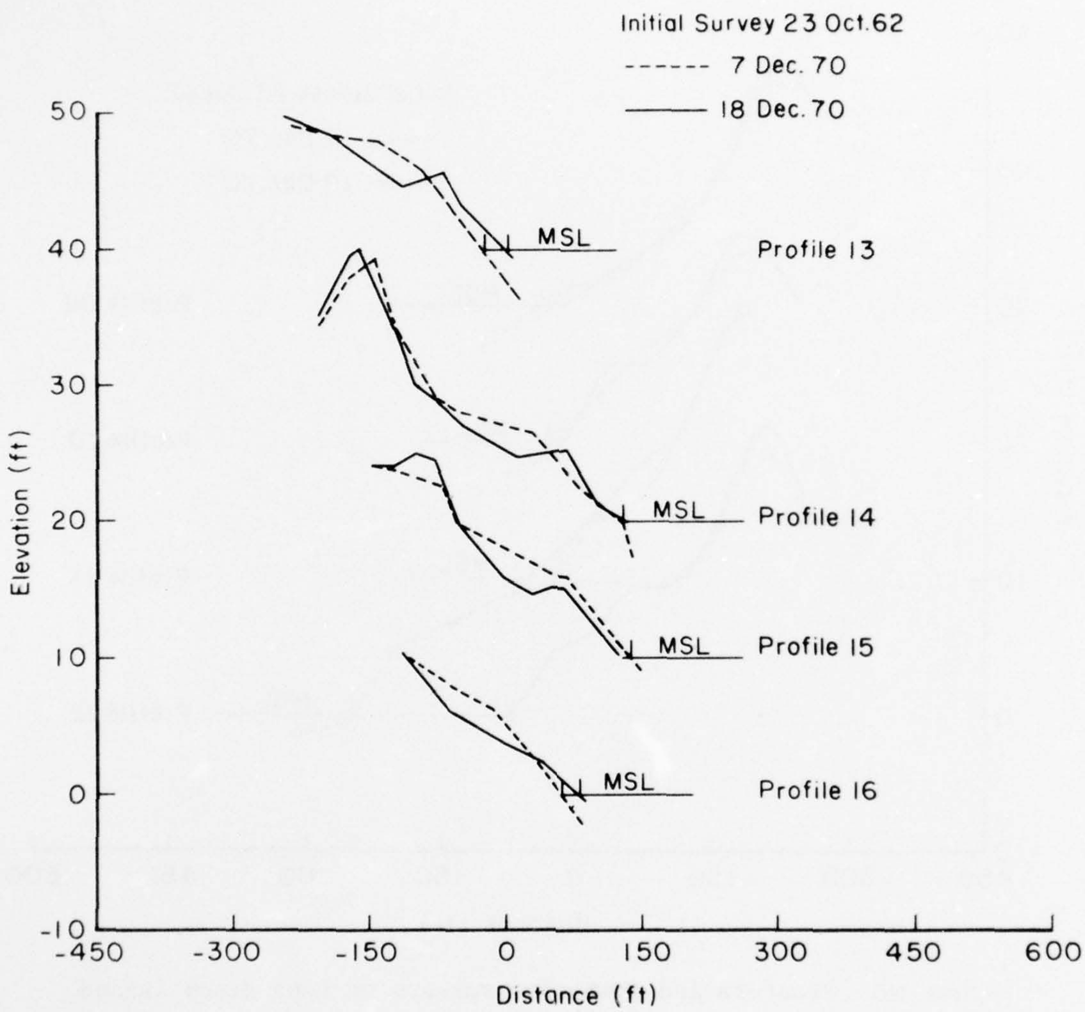


Figure 18. Prestorm and poststorm surveys at Long Beach Island, New Jersey.--Continued

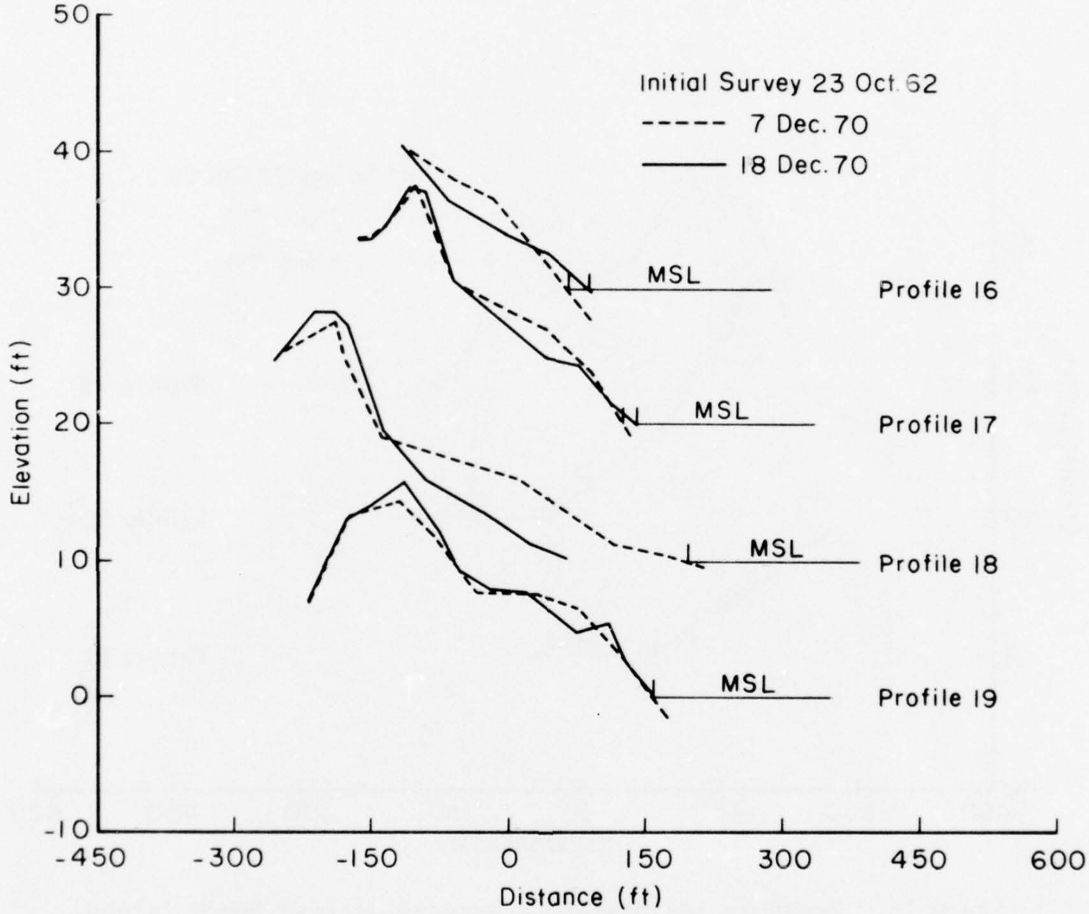


Figure 18. Prestorm and poststorm surveys at Long Beach Island, New Jersey.--Continued

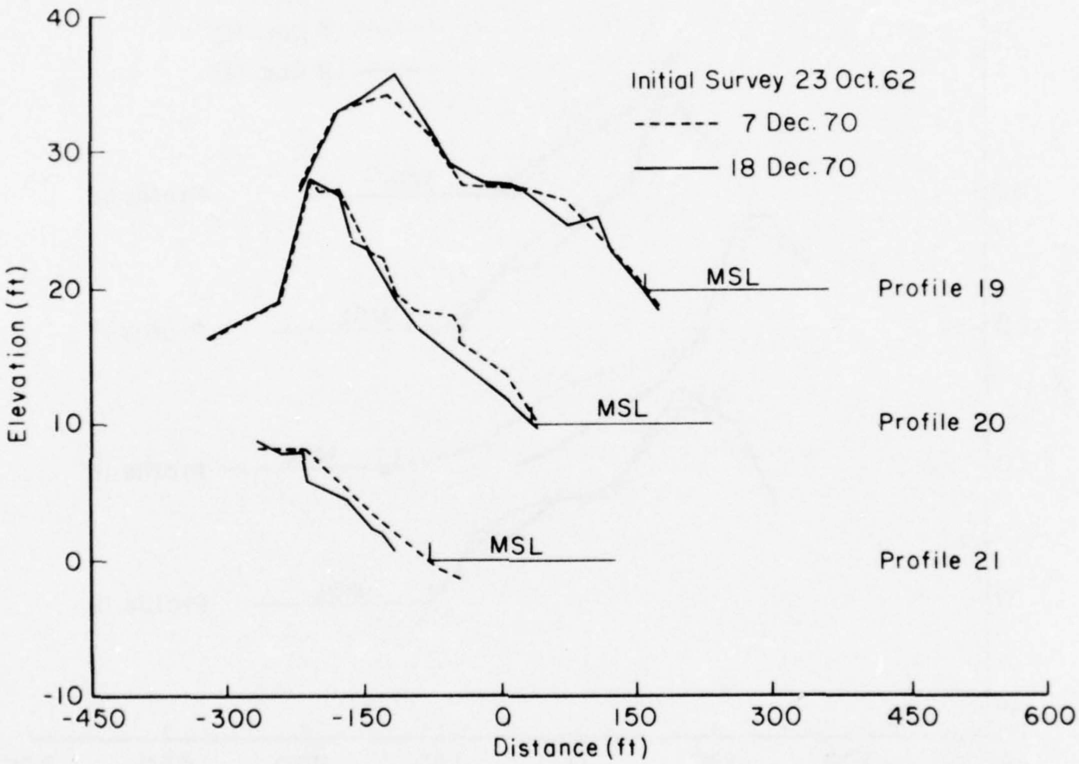


Figure 18. Prestorm and poststorm surveys at Long Beach Island, New Jersey.--Continued

Table 7. Shoreline and unit volume changes at Long Beach Island for 17 December 1970 storm.

Profile line	MSL shoreline change (ft)	PRCHAR[1] unit volume (yd^3/ft)	Plus 12[1] unit volume (yd^3/ft)
01	-5.5	-7.8	-7.8
02	8.7	-0.5	-0.7
03	25.0	1.6	4.7
04	-35.6	3.9	0.3
05	15.5	-4.5	-3.6
06	28.2	-2.7	-4.1
07	30.6	0.1	0.2
08	-23.1	-1.5	-5.3
09	-11.6	-0.3	-2.0
10	13.3	2.6	-1.1
11	28.9	-2.3	-3.2
12[2]			
13	23.1	-1.8	-1.8
14	----[3]	-3.4	-4.5
15	----[3]	-6.0	-8.7
16	17.5	-6.3	-6.3
17	9.4	-3.8	-4.9
18	----[3]	-20.8	-25.6
19	----[3]	1.6	-1.3
20	----[4]	-11.0	-10.2
21	----[3]	-5.9	-5.9
Average	8.9	-3.5	-4.4

[1]See Figure 8 for definitions.
[2]Questionable prestorm survey.
[3]Poststorm survey did not reach MSL.
[4]Prestorm survey did not reach MSL.

maximum erosion between the 16- and 14-foot contours. Profile line 04 accreted between the 8- and 5-foot contours, but significant erosion occurred at MSL. Although profile lines 09 and 18 showed erosion between the 8- and 5-foot contours, greater erosion occurred below the 5-foot contour. Accretion was observed on the lower part of most profile lines.

Those profile lines that indicated erosion on the lower ends generally eroded along the entire profile. Profile line 18, which is located approximately 260 feet south of a groin, showed accretion in the dune area (18- to 10-foot contours) with severe erosion occurring below the 8-foot contour.

Profile lines 01 and 02 are located inside Barnegat Inlet and are also within a field of six closely spaced groins. Profile line 01 eroded along the entire surveyed length (to -2 feet MSL), with maximum erosion between the 8- and 4-foot contours. Profile line 02 showed almost no change above the 1-foot contour; it accreted seaward to the -2-foot contour. Profile line 03 is located approximately 450 feet south of the Barnegat Inlet south jetty. This profile line showed significant accretion from the 13-foot contour to a depth of -1 foot, except for minor erosion at the 6- and 5-foot contours. From the 16- to 14-foot contours there was much erosion.

The average net volume change over 20 profile lines on Long Beach Island was -10.6 cubic yards per foot. Ten of the 14 profile lines that were surveyed to MSL had a positive or seaward MSL contour change between the prestorm and poststorm surveys; i.e., the poststorm survey showed accretion at MSL on 10 profile lines.

Pipe profiles were located along profile lines 13 and 16. At profile line 13, pipes 1 to 5 were read on 24 November and 18 December 1970. Maximum erosion at any one of the pipes was 3 feet, measured at pipe 3 where the sand level changed from 9.2 to 6.2 feet MSL. Maximum accretion at any one of the pipes was 1.5 feet, measured at pipe 5 where the sand level changed from 1.4 to 2.9 feet MSL.

At profile line 16, pipes 1 to 4 were read on both 25 November and 18 December 1970. Maximum erosion at any one of the pipes was 2.5 feet, measured at pipe 3 where the sand level changed from 6.4 to 3.9 feet MSL. Maximum accretion at any one of the pipes was 0.5 foot, measured at pipes 1 and 4.

Because the prestorm pipe readings were obtained more than 3 weeks before the storm, they are of limited use in judging the storm effects at this locality.

7. Atlantic City, New Jersey.

Profile line locations are shown in Figure 19, surveyed beach profiles in Figure 20, and MSL contour and area changes in Table 8. Extensive accretion was observed on profile line 01, which appears to be caused

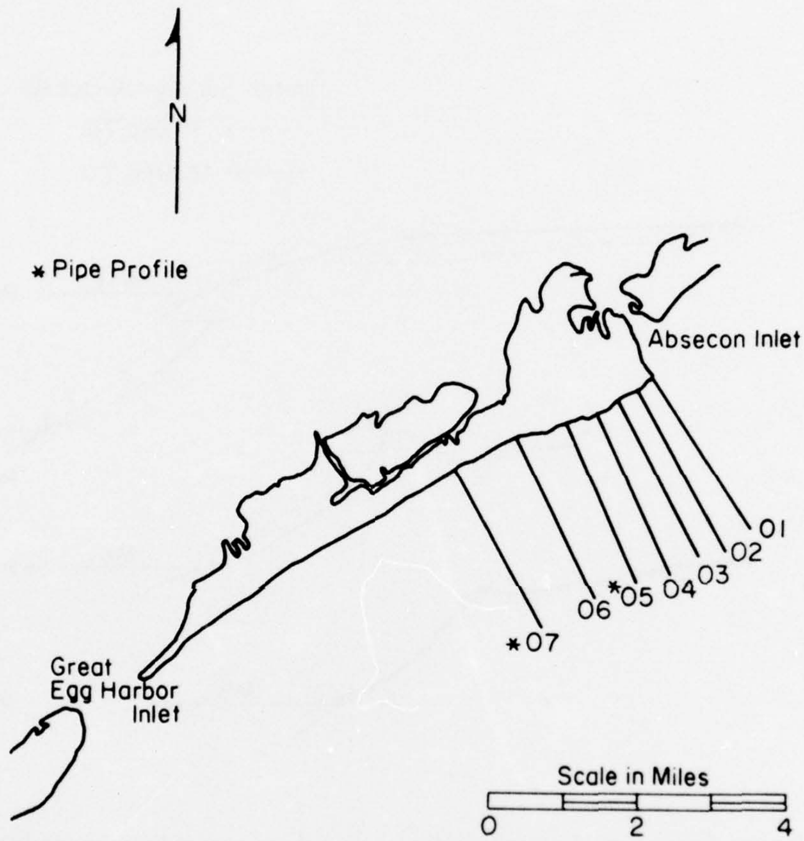


Figure 19. Profile line locations, Atlantic City, New Jersey.

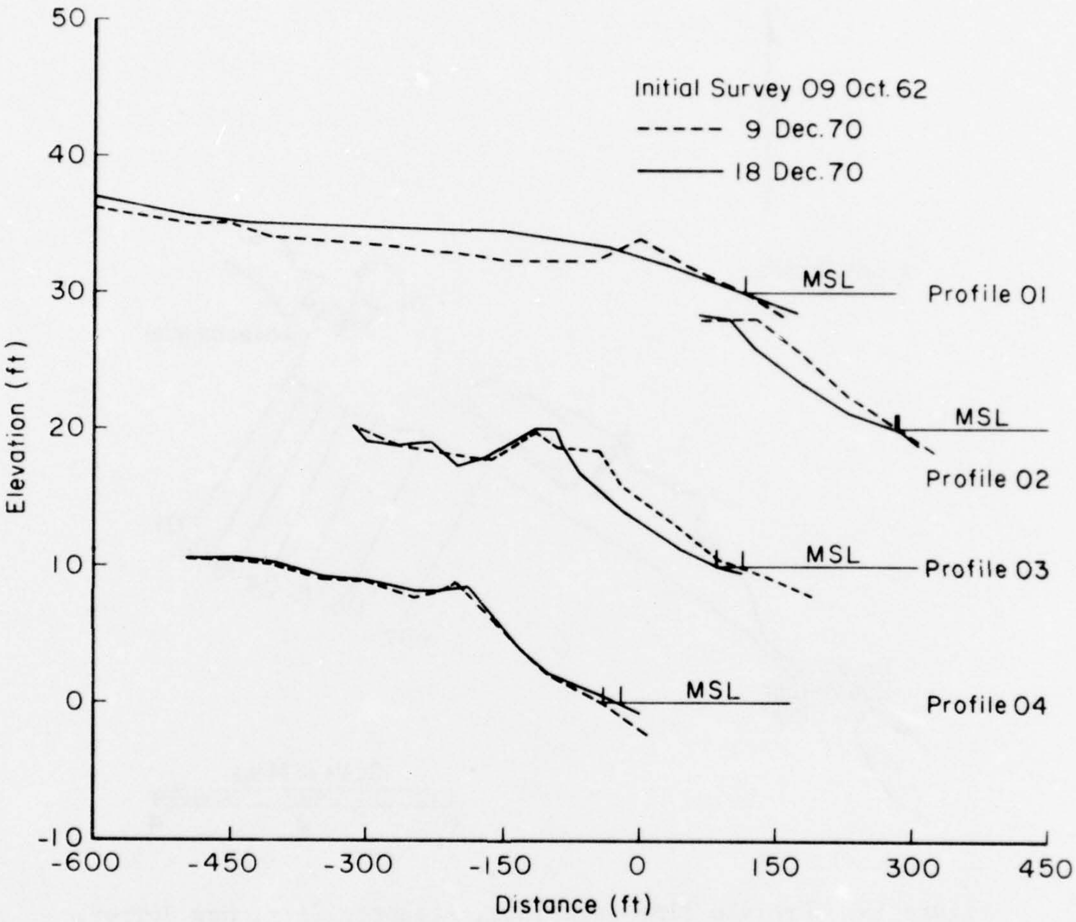


Figure 20. Prestorm and poststorm surveys at Atlantic City, New Jersey.

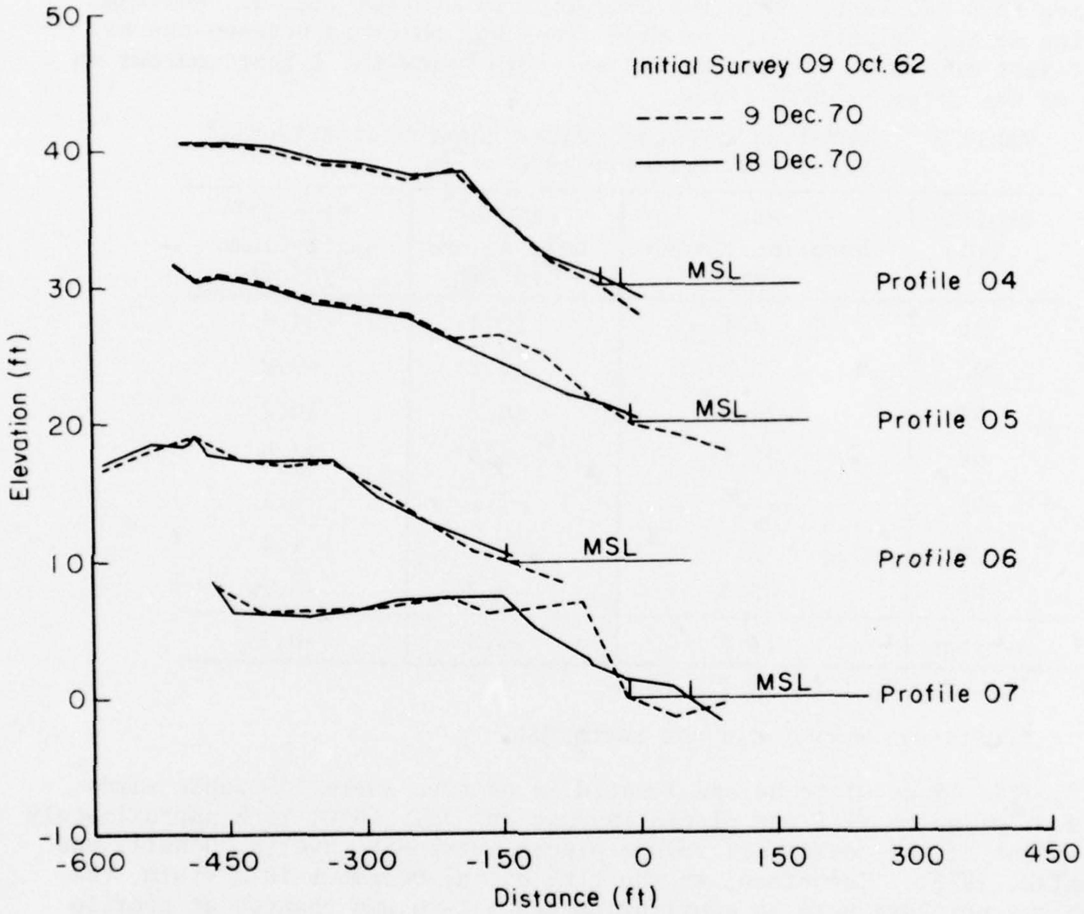


Figure 20. Prestorm and poststorm surveys at Atlantic City, New Jersey.--Continued

by its location immediately south of the Absecon Inlet jetty. The beach is very broad and flat, due to the fillet joining the shoreline from the jetty to the normal coast. The profile showed some erosion between the 2-foot and MSL contours, with substantial accretion occurring above the 3-foot contour, where the sand level accreted 1 to 2 feet over a distance of more than 500 feet. With the exception of profile line 01, maximum erosion at the Atlantic City profile lines was observed between the 6- and 4-foot contours. Accretion was observed below the 1-foot contour on five of the seven profile lines.

Table 8. Shoreline and unit volume changes at Atlantic City for 17 December 1970 storm.

Profile line	MSL shoreline change (ft)	PRCHAR[1] unit volume (yd^3/ft)	Plus 12[1] unit volume (yd^3/ft)
01	2.4	24.4	24.4
02	-3.7	-9.2	-9.2
03	-24.6	-10.2	-10.2
04	21.3	-3.9	-3.9
05	----[2]	-7.1	-7.1
06	-----	1.4	1.4
07	63.0	-5.2	-5.2
Average	11.6	-0.3	-0.3

[1]See Figure 8 for definitions.

[2]Poststorm survey did not reach MSL.

Profile lines 01 to 04 are located in an area where 165 cubic yards per foot of beach fill was placed in June and July 1970, with approximately 48 percent of the total fill volume placed above MSL (Everts, DeWall, and Czerniak, 1975). Therefore, at the time of the December 1970 storm, the beach may not have been in equilibrium and net-volume changes at profile lines 01 to 04 could reflect this condition.

The average net volume change above MSL on the seven Atlantic City profile lines was -0.3 cubic yards per foot. This figure is heavily weighted by profile line 01, which showed the maximum accretion (24.4 cubic yards per foot) measured in this study. Excluding profile line 01, the average net change was -4.4 cubic yards per foot.

Pipe profiles were located along profile lines 05 and 07. At profile line 05, pipes 1 to 8 were read on both 24 November and 18 December 1970. Maximum erosion at any one of the pipes was 1 foot, measured at pipe 8 where the sand level changed from 4.1 to 3.1 feet MSL. There was no accretion at any of the pipes.

At profile line 07, pipes 1 to 9 were read on both 24 November and 19 December 1970. Maximum erosion at any one of these pipes was 4 feet, measured at pipe 8 where the sand level changed from 5.2 to 1.2 feet MSL. There was no accretion at any of the pipes at profile line 07.

The prestorm pipe readings were taken more than 3 weeks before the storm, which limits their usefulness in judging the effects of the storm.

8. Ludlam Island, New Jersey.

Profile line locations are shown in Figure 21, surveyed beach profiles in Figure 22, and MSL contour and area changes in Table 9. Many of the profile lines on Ludlam Island have exposures of peat beds cropping out on the low tide terrace; scarps formed by the peat bed outcrops are probably the cause of apparent discontinuities near MSL on profile lines 05 and 07. Peat affords some protection to these profile lines by absorbing or reflecting some of the energy of the breaking waves. During storms such as this one, the peat is ripped up and the peat blocks are deposited higher up on the beach. As it is reworked, the peat disintegrates into particulate silt, clay, and organic material which, as suspended sediment, gives the surf a yellowish color. The disintegrated peat does not remain on the beach.

There are approximately 20 shore-protective structures on Ludlam Island, between Corson Inlet and the town of Sea Isle City. Profile line 04 was surveyed immediately adjacent to a timber groin, and profile lines 03, 11, 12, 13, 14, and 15 are located within 400 feet of a groin.

All profile lines except lines 10, 11, 17, and 20 showed net erosion. For some profiles, minor accretion was observed in the dune area and below the 1-foot contour. A poststorm field inspection of selected profile lines on Ludlam Island indicated that the accretion in the dune area is probably due to a buildup of eolian material along the sand fences. Photos show an accumulation of fresh sand on the seaward side of the sand fence at profile lines 10 and 16.

Profile line 20, located about 400 feet north of Townsend Inlet, showed anomalous accretion along its entire length except for minor erosion at the 3-foot contour.

The average net volume change above MSL on 19 Ludlam Island profile lines was -2.6 cubic yards per foot; the average MSL contour change was -1.6 feet.

Pipe profiles were located along profile lines 05 and 18. At profile line 05, pipes 1 to 4 were read on both 13 and 19 December 1970. There was no erosion at any of the pipes. Maximum accretion at any of the pipes was 1.0 foot, measured at pipe 4 where the sand level changed from 0.8 to 1.8 feet MSL.

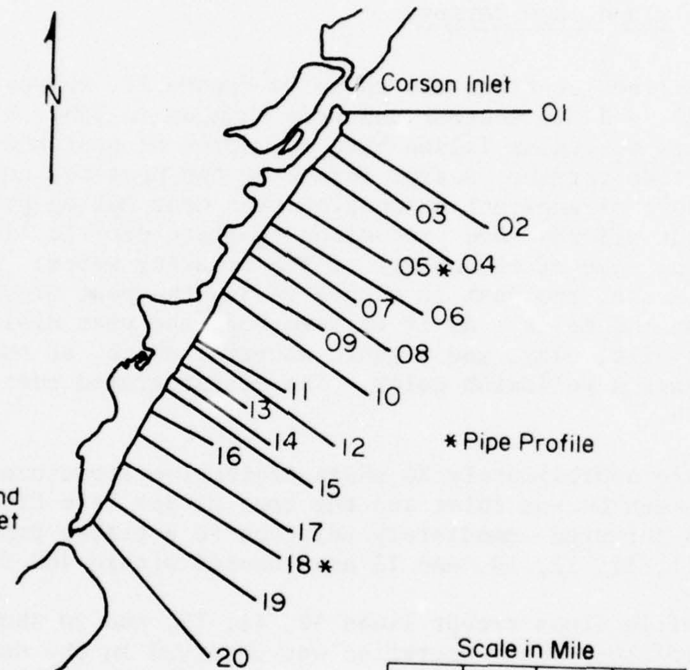


Figure 21. Profile line locations, Ludlam Island, New Jersey.

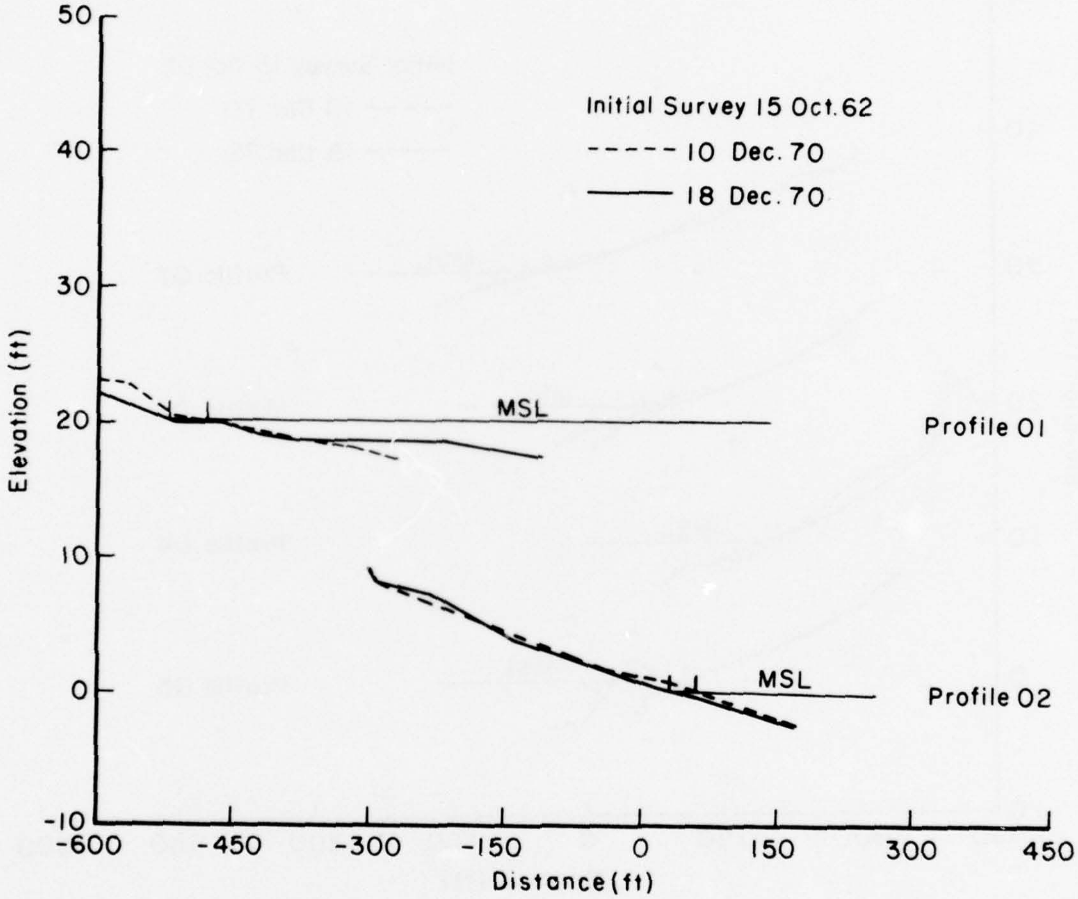


Figure 22. Prestorm and poststorm surveys at Ludlam Island, New Jersey.

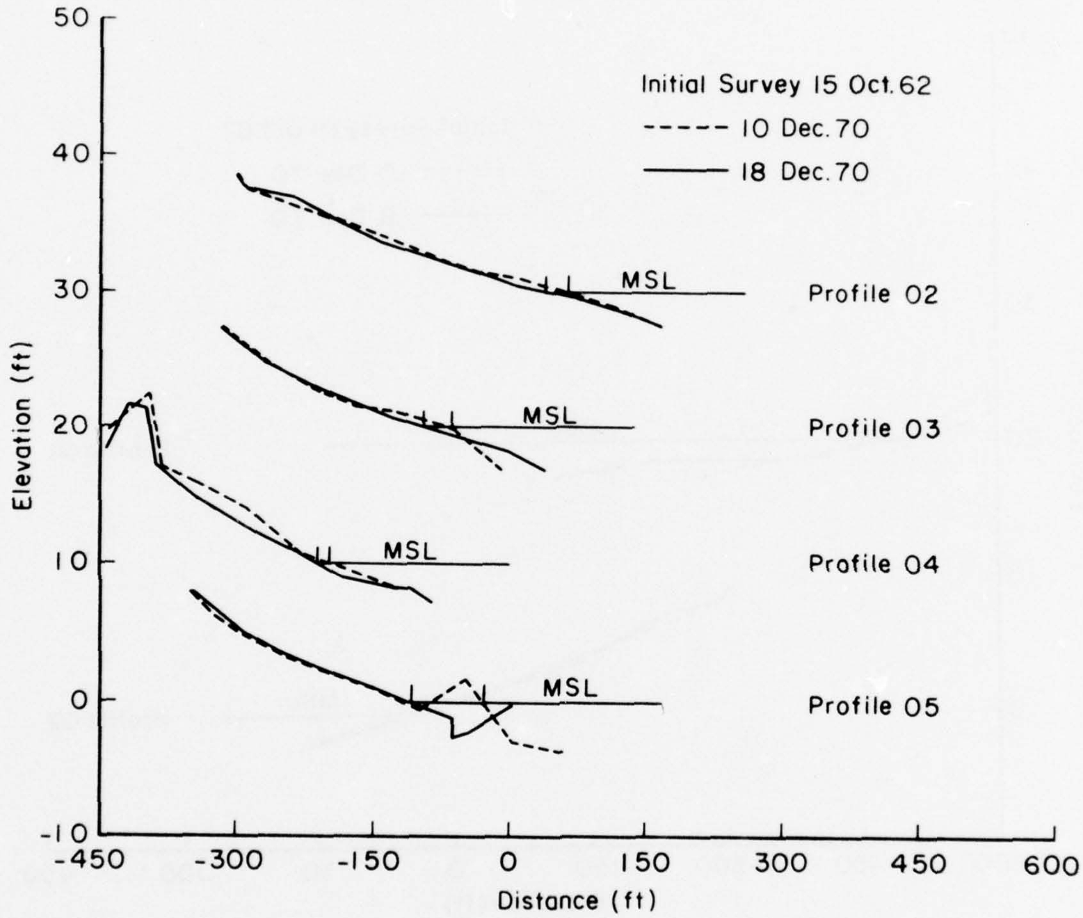


Figure 22. Prestorm and poststorm surveys at Ludlam Island, New Jersey.--Continued

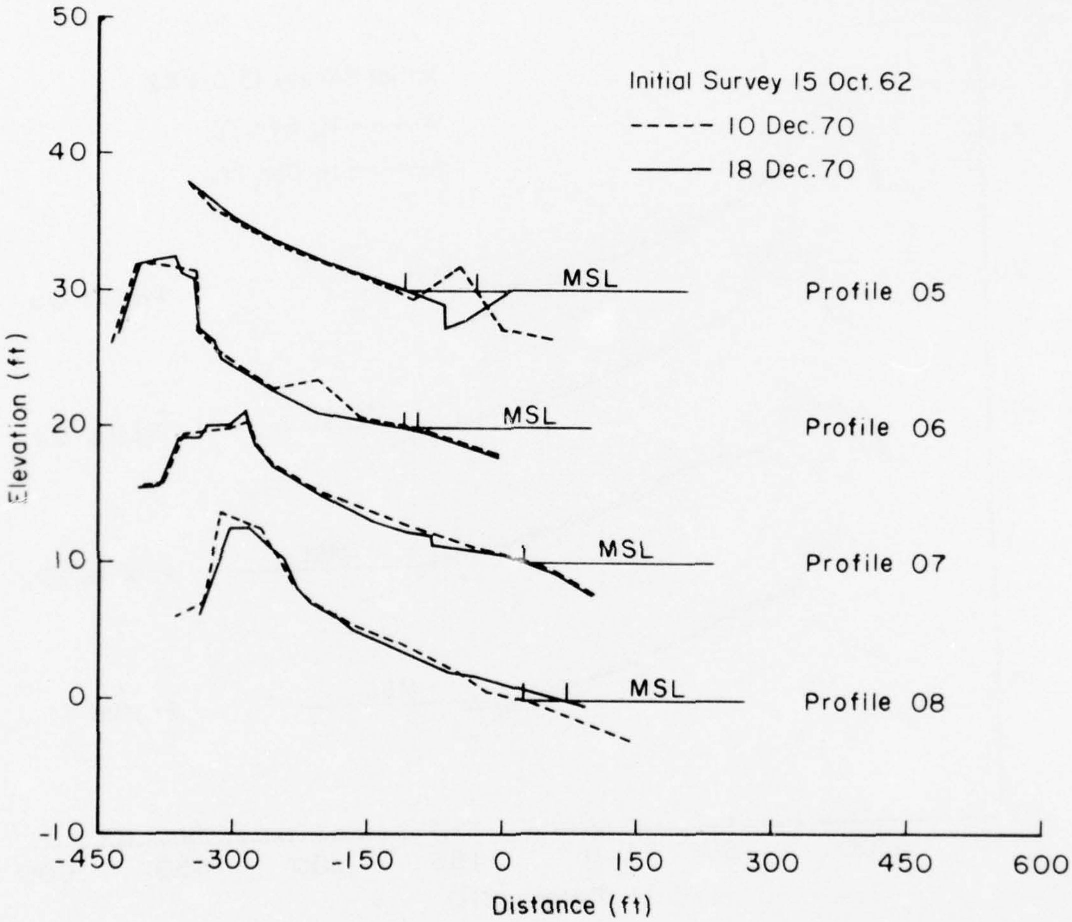


Figure 22. Prestorm and poststorm surveys at Ludlam Island, New Jersey.--Continued

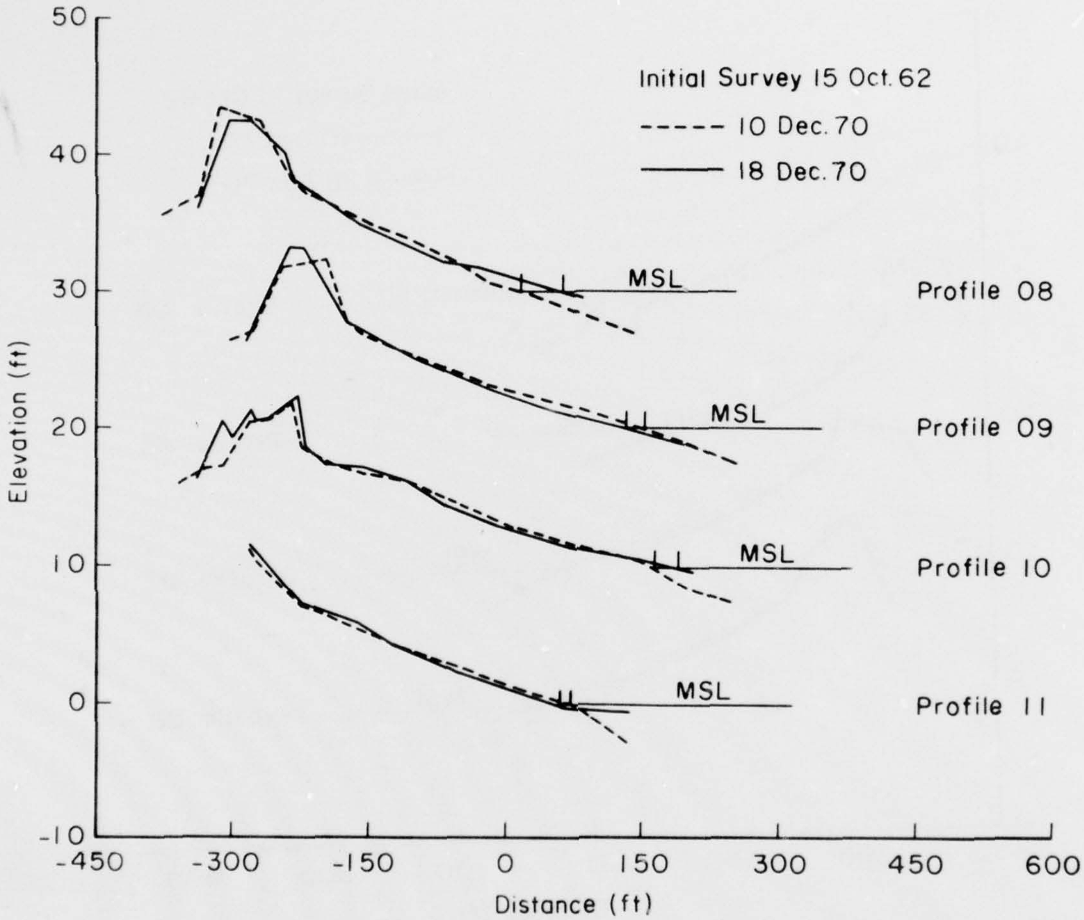


Figure 22. Prestorm and poststorm surveys at Ludlam Island, New Jersey.--Continued

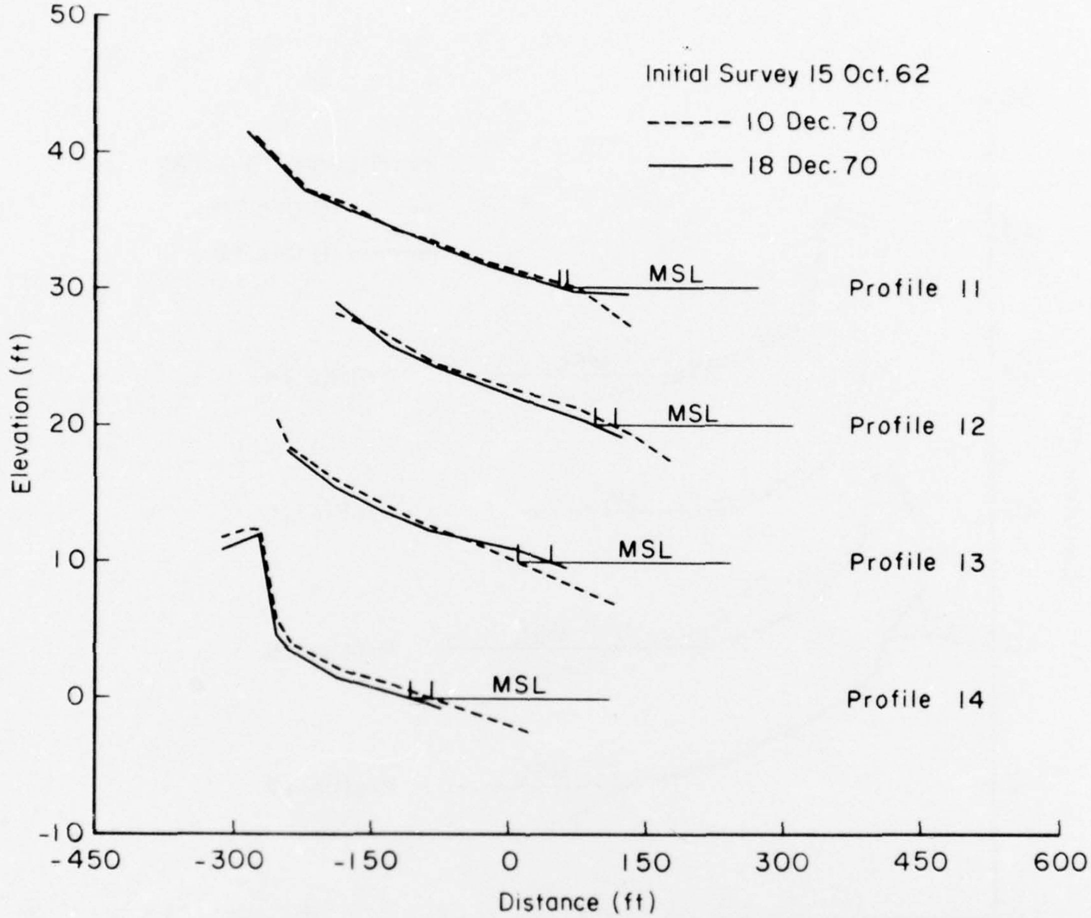


Figure 22. Prestorm and poststorm surveys at Ludlam Island, New Jersey.--Continued

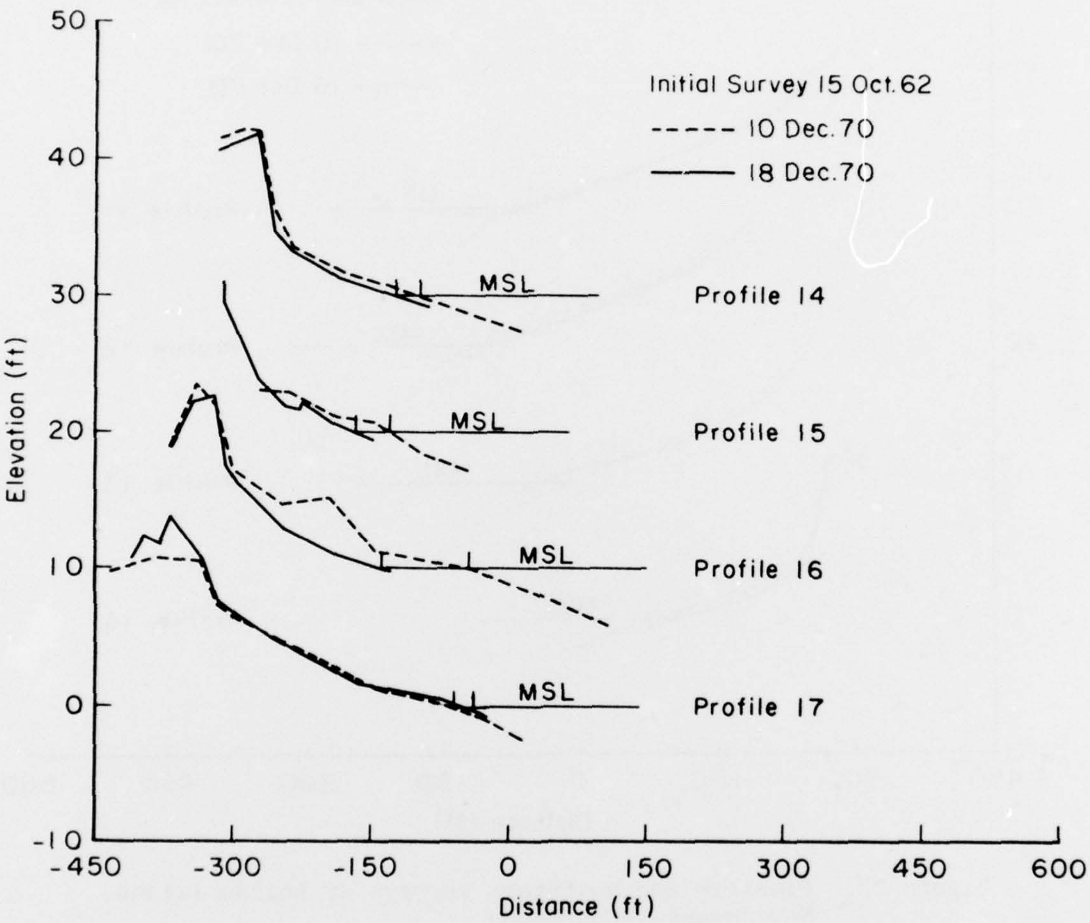


Figure 22. Prestorm and poststorm surveys at Ludlam Island, New Jersey.--Continued

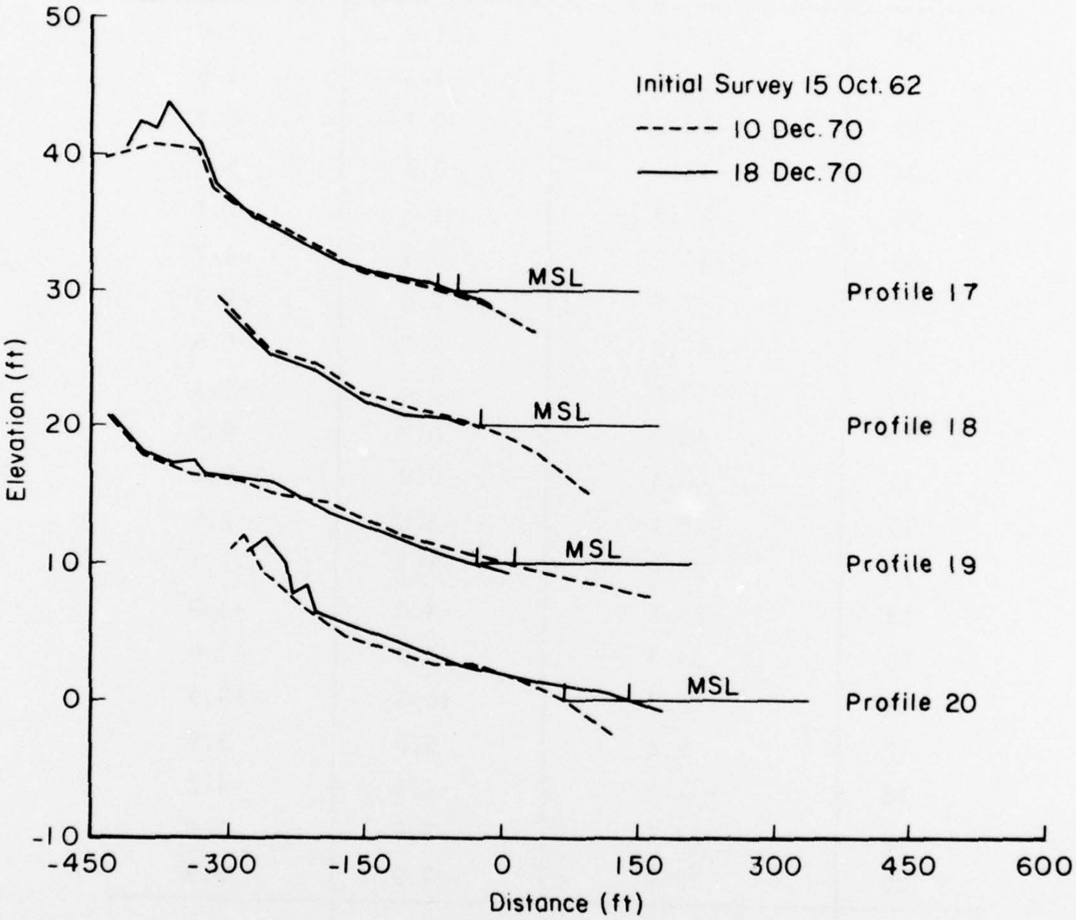


Figure 22. Prestorm and poststorm surveys at Ludlam Island, New Jersey.--Continued

Table 9. Shoreline and unit volume changes at Ludlam Island for 17 December 1970 storm.

Profile line	MSL shoreline change (ft)	PRCHAR[1] unit volume (yd^3/ft)	Plus 12[1] unit volume (yd^3/ft)
01	-53.8	-11.0	-11.0
02	-21.4	-1.5	-1.5
03	-22.2	-0.7	-0.7
04	-18.1	-5.7	-5.7
05	-83.5	-1.1	-1.1
06	-16.7	-5.1	-4.7
07	-7.7	-2.6	-2.6
08	47.9	-1.7	-0.5
09	-17.0	-3.3	-4.1
10	18.6	0.9	0.8
11	-6.4	0.0	0.0
12	-22.1	-3.5	-3.5
13	35.8	-1.1	-1.1
14	-23.5	-4.0	-3.9
15	-35.4	-2.9	-2.9
16	-96.3	-16.3	-15.9
17	6.8	5.0	3.9
18	----[2]	-4.2	-4.2
19	-37.5	-3.0	-3.0
20	72.7	9.9	9.9
Average	-1.6	-2.6	-2.6

[1]See Figure 8 for definitions.
[2]Poststorm survey did not reach MSL.

At profile line 18, pipes 1, 2, and 3 were read on both 25 November and 19 December 1970. Maximum erosion at any one of the pipes was 0.5 foot, measured at pipe 4 where the sand level changed from 2.5 to 2.0 feet MSL. There was no accretion at any of the pipes.

VI. DISCUSSION

Changes in the MSL contour position and unit volume were tabulated for each locality and summarized in Figures 23 and 24. For 78 of the 91 profile lines surveyed, both prestorm and poststorm surveys reached the MSL contour. The MSL change and the volume changes at each of these 78 profile lines are plotted in Figure 25. Only 57 of the 78 plotted profiles show like changes in sign; i.e., volume increases when shoreline accretes or volume decreases when shoreline retreats, although it is often assumed that the two parameters (volume change and shoreline position change) are equally good indicators of erosion or accretion.

Of the 21 profile lines showing a negative correlation between volume change and MSL contour change (one increases when the other decreases), all but 2 lost volume and accreted at the shoreline (Fig. 25). A good example of the negative relation between changes in MSL and unit volume can be seen on Cape Cod profile line 01 (Fig. 10). The prestorm MSL contour intercept occurs at +4.8 feet. The poststorm survey indicates erosion on the upper profile and accretion on the lower end of the profile as a bar. The crest of the poststorm bar was about 1.5 feet above the MSL contour, which resulted in triple intercepts of the MSL contour with the profile at -51.0, +21.2, and +91.5 feet. Thus, the most seaward shoreline shifted 86.7 feet seaward; the volume at the profile was actually reduced by 65.0 cubic yards per foot between MSL and +52 feet.

The only two profile lines to show a net increase in unit volume with a net retreat in shoreline were Jones Beach profile line 08 and Long Beach Island profile line 04.

For the 17 December 1970 storm, it can be concluded that a shift in the MSL contour is generally proportional to unit volume changes on the profile above MSL. Usually, a retreat in the MSL contour is accompanied by a unit volume loss from the beach profile above MSL, but in a significant number of cases, a decrease in unit volume is not accompanied by a retreat in the MSL shoreline.

The dashline in Figure 25 shows the rule of thumb relating permanent volume loss to permanent shoreline shift (1 cubic yard per foot for a 1-foot shoreline change, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1975, Vol. 1, p. 4-122). The nonpermanent storm loss from above MSL is apparently much less than the rule of thumb.

Storm Surge Elevation and Duration versus Maximum Erosion Elevation.

Maximum water elevations, maximum observed wave heights, and contours of maximum erosion for each locality surveyed are summarized in Table 10.

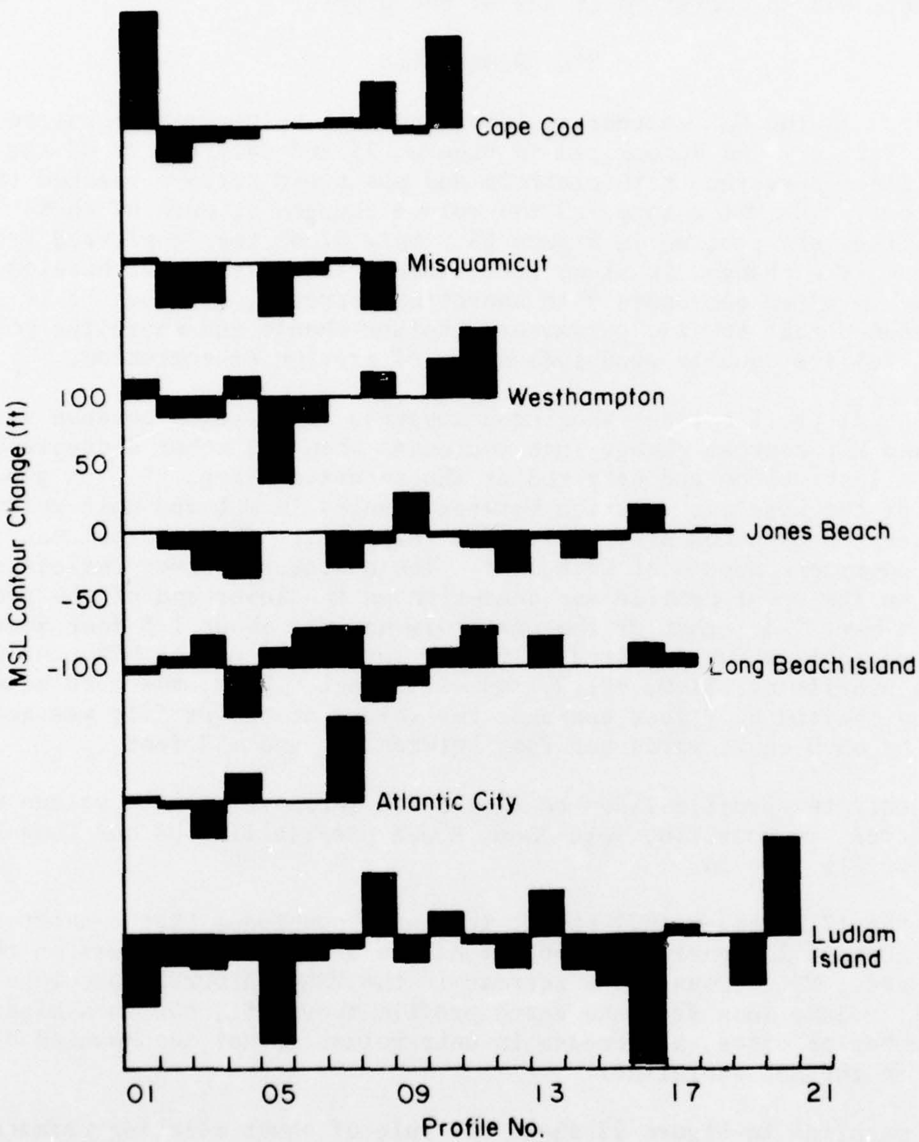


Figure 23. MSL contour changes, 17 December 1970 storm.

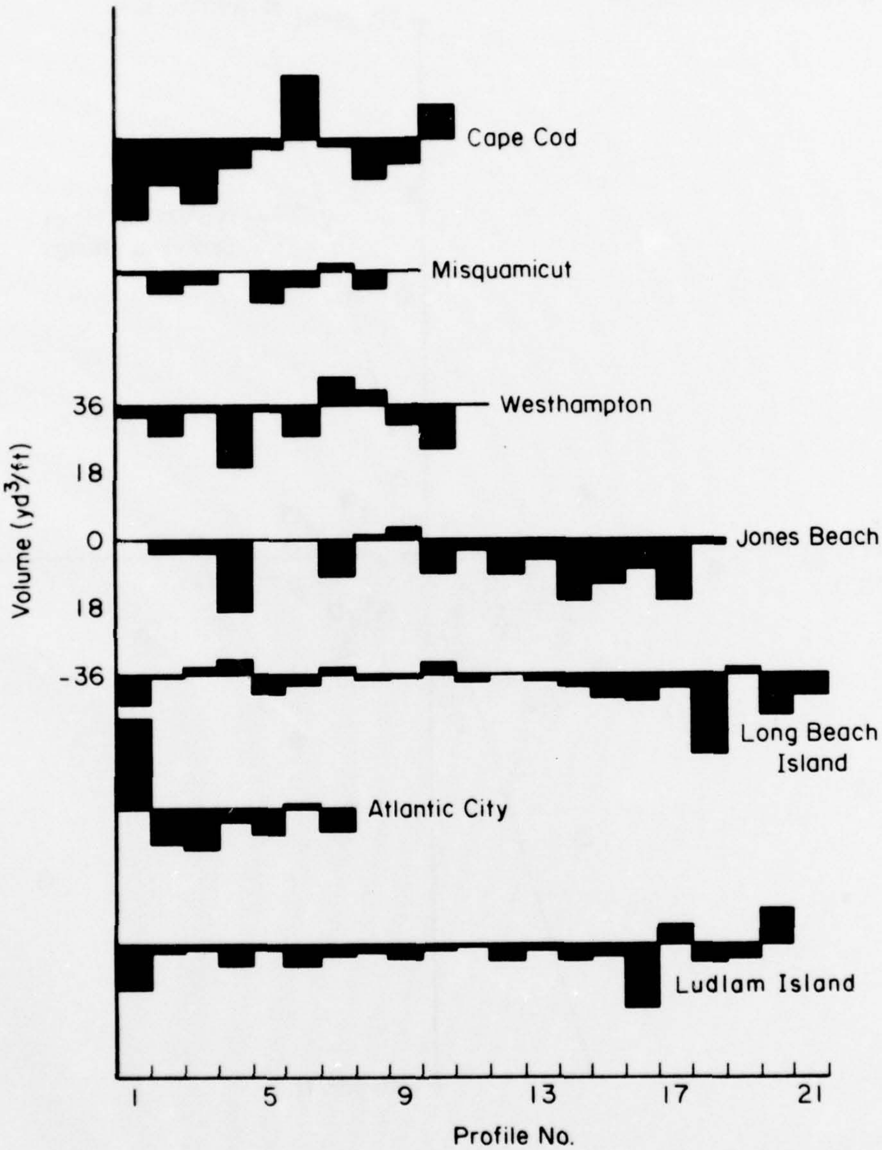


Figure 24. Unit volume beach changes, 17 December 1970 storm.

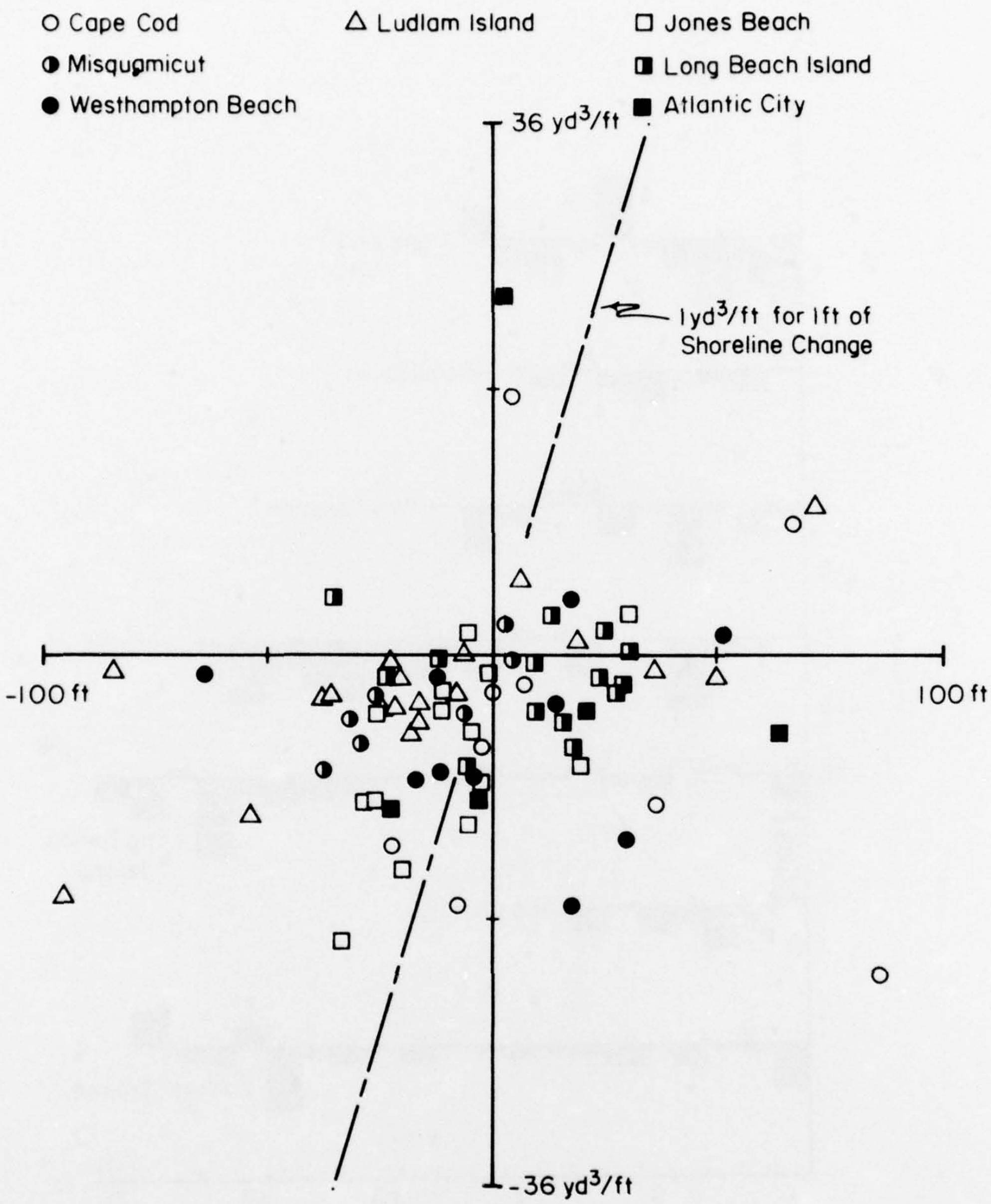


Figure 25. Volume change versus change in MSL contour, 17 December 1970 storm.

Table 10. Elevations of maximum water and beach changes, 17 December 1970 storm.

Locality	Maximum water elevation (ft above MSL)	Maximum observed wave ht. (ft)	Contours of maximum erosion (ft above MSL)	Contours of maximum accretion (ft above MSL)
Cape Cod	5.9	10.0	2 to 12	1 and below
Misquamicut	3.8	5.0	4 to 8	None
Westhampton	5.0	6.0	6 to 8	3 and below
Jones Beach	4.7	10.0	4 to 8	1 to 3
Long Beach Island	4.4	8.0	5 to 8	3 and below
Atlantic City	4.4	11.0[1]	2 to 6	1 and below
Ludlam Island	4.4	4.5	2 to 5	8[2]

[1]Wave gage data.
[2]Assumed to be eolian deposition.

The elevations of maximum average erosion and accretion correspond reasonably well with the maximum water elevation. Maximum erosion occurred at, or slightly above, the maximum water elevation; maximum deposition was observed below this elevation. On those beaches where maximum erosion occurred at significantly high elevations (principally Cape Cod), the loss was probably due to slumping of material from scarps made unstable by wave scour at the scarp base.

Because the storm moved rapidly northward (Fig 2), the accompanying surge was effective through less than two tidal cycles.

VII. CONCLUSIONS

1. As a result of the 17 December 1970 storm, 80 percent of 89 surveyed profile lines suffered an average net volume loss of 6.5 cubic yards per foot, between MSL and the maximum elevation contour surveyed for each profile line. (These data omit profile lines 06 on Cape Cod and 12 on Long Beach Island which appear questionable.) Storm intensity is expected to be equaled or exceeded about twice a year.

2. The maximum recorded erosion was 21.7 cubic yards per foot on Cape Cod profile line 01, which included loss from the cliff behind the beach. The maximum recorded accretion was 24.4 cubic yards per foot at the Atlantic City profile line 01, which is immediately adjacent to the Absecon Inlet jetty and in an area of a beach fill made a few months earlier.

3. The larger vertical changes in sand level (4 to 5 feet) were observed on the coarser, steeper beaches of Cape Cod and Long Island; the maximum horizontal change in the MSL contour of -96.3 feet was observed on the finer, flatter beaches of Ludlam Island.

4. Profile contours of maximum erosion correlated reasonably well with maximum water elevation obtained from tide and surge data and were generally between +4 and +8 feet MSL. Accretion was generally observed near the MSL contour, except at Ludlam Island, where eolian accretion in the dunes was more significant.

5. Extrapolation from surveyed profiles indicates that a minimum of 10.1 million cubic yards of sand was moved from the beach above MSL along about 450 miles of ocean front between Cape May, New Jersey, and Race Point, Massachusetts, as a result of this storm. This volume, equivalent to 4.4 cubic yards per foot, compares with 3.2 to 9.5 cubic yards per foot computed by Shuyskiy (1970) for a storm in the eastern Baltic Ocean in October 1967. Data from Harrison and Wagner (1964) indicate that the average erosion of the dunes at Virginia Beach, during the March 1962 storm, was on the order of 4.4 cubic yards per foot. For four storms at Atlantic City between November 1963 and February 1972 (including the 17 December 1970 storm) an average loss of 5.2 cubic yards per foot per storm was estimated, based on BEP surveys (Everts, DeWall, and Czerniak, 1975).

For storms affecting Jones Beach in February 1972, the net loss of beach material over 10 profiles averaged 9.0 cubic yards per foot for the first storm and 9.6 cubic yards per foot for the second (Everts, 1973). In this Jones Beach case, profiles at either end of the beach, which tend to accrete, were omitted from this study, and even then several of the profiles showed net accretion.

6. Pipe profile data obtained at Westhampton Beach indicate the importance of obtaining poststorm survey data as rapidly as possible. Sand level observations made at the pipes during the storm indicate that the sand level was 3 feet lower on the foreshore during the storm than it was when surveyed the next day. During the day following the storm, the sand level on the foreshore was observed to recover 1 foot in less than 2 hours.

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